

BIOLOGY



MARINE BIOLOGICAL LABORATORY.

Received June 27, 1939

Accession No. 50458

Given by American Book Co.

Place, New York City

**No book or pamphlet is to be removed from the Laboratory without the permission of the Trustees.



BIOLOGY

The Story of Living Things

GEORGE WILLIAM HUNTER

*Lecturer in Methods of Science Teaching
Department of Education
Claremont Colleges*

HERBERT EUGENE WALTER

Professor of Biology, Brown University

GEORGE WILLIAM HUNTER, III

Assistant Professor of Biology, Wesleyan University



AMERICAN BOOK COMPANY

NEW YORK	CINCINNATI	CHICAGO
BOSTON	ATLANTA	SAN FRANCISCO
DALLAS		

COPYRIGHT, 1937, BY
AMERICAN BOOK COMPANY

All rights reserved

COLLEGE BIOLOGY, H. W. & H.
W. P. 2

MADE IN U. S. A.

*This book is gratefully dedicated to our wives, to whom
much of the credit and none of the blame is due.*

PREFACE

HERE ARE a few chips left over from the authors' workshop.

First of all we do not pretend to have presented herein the last word in a field already overcrowded by worthy rivals. The "last word" has an undesirable mortuary connotation quite out of keeping in a book about living things.

The authors have been teaching biology for a total of ninety-four academic years, in addition to over sixty seasons of strenuous service in summer field work with classes at marine and fresh-water laboratories, and they can truthfully and enthusiastically say that they have enjoyed this experience.

If what they would pass on to other students of biology appears from the table of contents to bear the familiar marks of old stuff, the reason is that it represents, in their minds at least, what remains after many years of trial and elimination at the hands of an army of different teachers and scholars. The fact that much material that has been worked over before it was retained does not necessarily prevent, it is hoped, some degree of freshness in its presentation. Any textbook, the authors hold, should be somewhat like a dish of uncracked nuts, accompanied by a good substantial nutcracker. It is desirable that the reader should have some of the fun of wielding the nutcracker, for no pedagogical cellophane can preserve nuts already shelled in an entirely fresh and satisfactory condition for a very long time.

An inevitable handicap that the textbook method of presentation of any subject is bound to suffer, is the fact that between the covers of a book the whole banquet is set upon the table at once in a more or less complete array. It is the part of the instructor to break up the feast into courses and to serve them in digestible portions. Perhaps the method of suspense employed in magazine serials would furnish a better way of arriving at the desired end than presenting the matter all at once in book form, since sufficient time should always be provided between the planting and harvesting of intellectual ideas to allow for unforced sprouting and growth.

In the use of any textbook it is well to remember that the pages may be turned backward as well as forward, and that it is no crime either to skip or to reread.

Every studious and effective reader, moreover, is wary about

accepting without question whatever he may come across in print, for even textbooks are often known to be incomplete and liable to error.

Again, if the art of reading between the lines has not been cultivated, it does not greatly avail simply to scan the printed lines themselves. Every opening that induces the reader to seek further should be gratefully prized.

Goethe once said: "Wer nicht mit der Bewunderung anfängt, werdet nie in das innere Heiligthum eindringen." Wonder is truly the mother of wisdom, for once the capacity for wonder slips away, one is prone to become blasé, uncomfortably sophisticated, and intellectually slothful.

With this explanation of the way it is hoped that this book will be used, the authors unite in cordially inviting the reader to join them in exploring the following pages.

ACKNOWLEDGMENTS

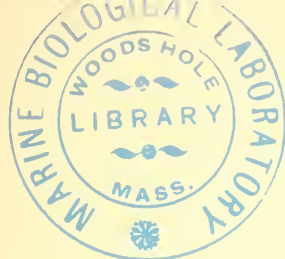
THE AUTHORS wish to make grateful acknowledgment to all who have aided them in the preparation of a college textbook in biology.

In particular, mention should be made of the members of the Biology Department of Wesleyan University who so willingly collaborated in trying out the ecological approach to a study of general biology for several years prior to publication of this book. Grateful acknowledgment is also made to them for innumerable suggestions as well as for their willingness to include certain successful features of the course in the text. Their help and advice has frequently been sought and willingly given.

Special mention should also be made of the tireless effort and willing help of Wanda S. Hunter and Alice Hall Walter, both of whom read the manuscript and proof and contributed much to whatever success this book may attain.

It is impossible here to enumerate all who have aided in the production of this book, but the following names must be mentioned: Dr. E. C. Schneider, Shanklin Biological Laboratory, Wesleyan University, for reading the entire manuscript; Dr. Francis R. Hunter, Rhode Island State College, for reading the entire proof; Dr. Aurel O. Foster, Gorgas Memorial Laboratory, Panama, for reading section XII; Dr. Hurbert B. Goodrich, Shanklin Biological Laboratory, Wesleyan University, for reading sections XIX-XXIII; Dr. Frederick L. Hisaw, Biological Laboratories, Harvard University, for reading section XVIII; Dr. John A. McGeoch, Psychological Laboratory, Wesleyan University, and Dr. Bernard C. Ewer, Department of Psychology, Pomona College, for reading section XVII; Dr. Philip A. Munz, Department of Biology, Pomona College, for reading the botanical portions of the book; Messrs. Emil Kotcher and Wilson C. Grant for aid in preparing the index.

Acknowledgment is also made to organizations and individuals without whose co-operation it would have been impossible to secure many of the instructive and attractive illustrations.



CONTENTS

NATURAL HISTORY

CHAPTER	PAGE
I. THE STAGE SETTING (ECOLOGY)	1
II. THE BIOLOGICAL CONQUEST OF THE WORLD	26
III. THE INTERDEPENDENCE OF LIVING THINGS—THE WEB OF LIFE	44
IV. ROLL CALL	63

FUNDAMENTALS OF STRUCTURE AND FUNCTION

V. LIFE AND PROTOPLASM	125
VI. CELLS AND TISSUES	138

ORGANISMS ILLUSTRATING BIOLOGICAL PRINCIPLES

VII. BEGINNINGS: THE LARGE GROUP OF THE SMALLEST ORGANISMS	151
VIII. THE DEVELOPMENT OF SEXUALITY IN PLANTS	168
IX. DIVISION OF LABOR IN COELENTERATES	179
X. BEING A WORM	187
XI. THE POPULAR INSECT PLAN	199
XII. THE ART OF PARASITISM	215
XIII. ADVANTAGES OF BEING A VERTEBRATE	233

THE MAINTENANCE OF THE INDIVIDUAL

XIV. THE RÔLE OF GREEN PLANTS	237
XV. THE METABOLIC MACHINERY OF ANIMALS	274
XVI. SUPPORT, MOTION, AND SENSATION	326
XVII. THE DISPLAY OF ENERGY	364
XVIII. CHEMICAL REGULATORS	390

THE MAINTENANCE OF SPECIES

XIX. REPRODUCTION AND LIFE CYCLES	405
XX. THE GREAT RELAY RACE	431

THE CHANGING WORLD

CHAPTER	PAGE
XXI. TIME SPENT (PALAEONTOLOGY)	473
XXII. THE EPIC OF EVOLUTION	483
XXIII. THAT ANIMAL, MAN (ANTHROPOLOGY)	530

MAN AS A CONQUEROR

XXIV. MAN'S CONQUEST OF NATURE	567
XXV. CONSERVATION AND ITS MEANING	589
XXVI. MAN'S FIGHT FOR SURVIVAL	608
XXVII. THE NEXT MILLION YEARS	637
INDEX	645

NATURAL HISTORY

I

THE STAGE SETTING (ECOLOGY)

PREVIEW. Ecology of a typical region · How to study ecology · Plant and animal associations · Basic environments: water as a factor; temperature; light as a factor; chemical factors; gravity as a factor; substratum; molar agencies; biotic factors · Life in the water · Life in the air · Life on land · Suggested readings.

PREVIEW

"My heart is fixed firm and stable in the belief that ultimately the sunshine and the summer, the flowers and the azure sky, shall become, as it were, interwoven into man's existence. He shall take from all their beauty and enjoy their glory." — RICHARD JEFFERIES: *The Life of the Fields*.

There is a lure in knowing something intimate about plant and animal neighbors, their habits and the places where they live. A trout fisherman finds almost as keen enjoyment in watching a kingfisher make its catch as in having a trout take his own fly. The banks, meadows, and woods along a trout stream are alive with interesting plants and animals. Even a slight acquaintance with what may be expected along the path makes a hike through the forest and field immensely more worth while. An early morning walk, if one knows a few permanent bird residents and can recognize a migrant here and there, takes on an absorbing interest for the observer. Such trips in the open are eventful experiences, the joy of which is not easily forgotten. One may see the beauty of living things, and enjoy the songs of birds and the gay colors of insects, or get a thrill out of the sight of the first violet or bluebird, as he drinks in the sweet odors of the flowery meadow. From the standpoint of the more observant, another side than passive enjoyment of nature is to be found. It is discovered in asking and trying to answer the *how* and *why* of life around us.

Charles Elton has called the science of ecology "scientific natural history." This deals with the occurrences and behavior of organisms in a given habitat or home. Anyone who feels a genuine response to the call from the natural environment surrounding him cannot

fail to find an interest in this approach to natural history. Why, for example, do certain kinds of animals live in the swift water of trout streams, while different ones are associated with plants in a quiet pond? Why are the types of life found along the seashore so unlike those around the edge of an inland lake? Why do forest trees grow tall in the dense woodland, more spreading in the open, and stunted near the tops of mountains? These and hundreds of like questions can be answered truthfully with the background afforded by the science of ecology.

Ecology of a Typical Region ¹

New England scenery is characterized by rounded granite hills, often heavily wooded with second or even third growth. In the hollows surrounded by these hills nestle little lakes, bodies of water varying in area from a few hundred square feet of surface to many scores or even square miles in extent.

A survey of the inhabitants of one of these smaller lakes, chosen as a typical example, reveals relatively few fish and fewer plants in the open water. Nearer shore are found unmistakable zoning of plants and animals, depending on whether the shore is rocky, sandy, or muddy. In sheltered bays having a bottom of soft mud are found numbers of pond lilies and other aquatic plants, which give shelter to pickerel, bass, and smaller fish, as well as a vast array of small crustaceans, insect larvae, and microscopic plants and animals.

Part of the lake shore is a sandy beach, at one end of which a sluggish stream, after meandering through a meadow, empties into the lake. This constitutes quite a typical environment and will yield abundant material if searched carefully.

The edge of the lake bordering on the beach contains relatively few plants and animals. It is exposed to the wind and consequently to wavelets which cause more or less movement of the loose sand, thus giving slight protection to living things. We find here almost no

¹ BOOKS USEFUL FOR FIELD WORK

Downing, *Our Living World*, Longmans, Green, 1924.

Johnson and Snook, *Seashore Animals of the Pacific Coast*, Macmillan, 1927.

Lutz, *Field Book of Insects*, Putnam, 1921.

Mann and Hastings, *Out of Doors*, Holt, 1932.

Morgan, *Field Book of Ponds and Streams*, Putnam, 1930.

Needham and Needham, *Guide to the Study of Fresh Water Biology*, 3rd ed., Comstock Publ. Co., 1935.

Weaver and Clement, *Plant Ecology*, McGraw-Hill, 1929.



J. S. Rankin, Jr

A slow-flowing stream presents a habitat for characteristic plants and animals adapted to this type of environment. Read pages 3-4.

plants and only occasional bass, pickerel, or minnows. A few dragonfly nymphs live under the small stones in shallow water, while numerous snails (*Campeloma*) are found buried in the sand or crawling along the bottom.¹ It is possible to collect a few specimens of plankton, which consists of minute free-swimming or floating organisms, but, on the whole, it is a relatively inhospitable environment inhabited by comparatively few organisms.

Within a few yards of this beach the stream flows gently over a shallow sandbar, flanked by cattails and rushes. Here are numerous representatives of several groups of plants: in the water a variety of algae, *Spirogyra* (pond scum), streaming filaments of *Oedogonium*, *Oscillatoria*, and *Cladophora*, and innumerable unicellular organisms, such as desmids and diatoms. Water cress, water plantain, water smart-weed, and burr-weed grow along the banks, while in sheltered bays the surface of the water may be covered with duckweed or perhaps yellow and white water lilies. Here and there in boggy places are dense masses of cattails, yellow flowering rushes, and numerous sedges, while on the banks are found grasses of several species.

¹It is expected that the student will make free use of IV, "Roll Call," for general identification and of the books of reference noted for more intimate and exact classification.

buttercups, Jack-in-the-pulpit, bog arrow-grass, and a few shrubs such as button-bush and willow. The vegetation shows a zonal arrangement of, first, submerged or floating water plants, then emergent forms, growing in the water and along the banks, while other plants such as grasses and shrubs are found at a little distance from the water. This zonal distribution is characteristic of shore associations of plants and animals.

In the slow-flowing stream live two species of sunfish, two or three species of pickerel, bass, three species of frogs, bullfrogs, green frogs, and pickerel frogs with their tadpoles, also an occasional painted turtle and water snake. Of birds, the redwing blackbirds are numerous, with occasional kingfishers, and more rarely a great blue heron. Although no mammals are in sight, a telltale mound of sticks shows that muskrats live there. Of the smaller organisms, the nymphs and larvae of the dragonfly and Mayfly are the most abundant. The water swarms with two species of water bugs and diving beetles, while beetle larvae and the larvae of mosquitoes are numerous. Many crustaceans, tiny amphipods and isopods, may be seen swimming or feeding on the aquatic plants. The snails, *Physa* and *Lymnaea*, are very abundant, while a few aquatic worms, *Tubifex*, may be found in the mud. Colonies of bryozoans may also be found, incrusting the stems of water plants, as well as an occasional mass of fresh-water sponge.

These two regions, the lake shore and the stream, although only a few yards apart, present tremendous differences in populations. Why these differences? At first sight, one might say it was due entirely to abundance of food, but this is only begging the question. Evidently many factors are at work. The fauna and flora of other localities visited would show even greater changes. Across the meadow and up into the nearby woods each locality would be found to be inhabited by groups of living plants and animals differing in many respects from those in neighboring localities. In each of these localities there would be certain dominant organisms better fitted than any others to live there. These become permanent species in that locality.

How to Study Ecology

To understand much about ecology, one must be able to do much more than simply study a book. The place to study the stage setting is the stage. The place to learn about the relation of living things

to their environment is the habitat. Elton¹ in his interesting introduction to ecology describes the attack on a certain ecological problem in these words:

"Suppose one is studying the factors limiting the distribution of animals living in an estuary. One would need to know amongst other things what the tides were (but not the theories as to how and why they occur in a particular way); the chemical composition of the water and how to estimate the chloride content (but not the reasons why silver nitrate precipitates sodium chloride); how the rainfall at different times of the year affected the muddiness of the water; something about the physiology of sulphur bacteria which prevent animals from living in certain parts of the estuary; the names of common plants growing in salt-marshes; something about the periodicity of droughts (but not the reasons for their occurrence). One would also have to learn how to talk politely to a fisherman or to the man who catches prawns, how to stalk a bird with field-glasses, and possibly how to drive a car or sail a boat. Knowing all these things, and a great deal more, the main part of one's work would still be the observation and collection of animals with a view to finding out their distribution and habits."

This gives us our approach. Our own interests, our reading, and the time involved must largely determine the extent to which we solve the ecological problems of our own environment.

Plant and Animal Associations

In making an ecological study of living communities we notice that one kind of plant or one kind of animal is never found living entirely alone. Plants, for example, are associated together by lack or abundance of water; those living under abundant water conditions being called *hydrophytes*; those associated in a condition of moderate



Water lilies, cattails, and bulrushes are characteristic hydrophytes.

¹ From Elton, Charles, *Animal Ecology*, p. 35. By permission of The Macmillan Company, publishers.



Typical xerophytic plants of the desert areas.

Haworth

water supply, *mesophytes*; and those which associate in desert conditions, *xerophytes*. Animals which live in the water are said to be *aquatic*, those on land *terrestrial*, while those that live both on land and in water are called *amphibious*. Animals and plants associated in still water are quite different from those in running water, while different types of plants and animals are found close to shore, in deep water, in rapid water, on rocky shores or on sandy shores, in salt or in fresh water, and in tidal pools or on the sand. Everywhere we find different associations of plants and animals. Many explanations are given, but no one explains everything. One investigator, Merriman, emphasizes temperature as an all-important factor; Walker gives atmospheric pressure; Heilprin, food; and Shelford, in recent experiments, indicates that the conditions under which an animal breeds may greatly influence its distribution. He experimented with tiger beetles, using different soils such as clay, clay and humus, humus, humus and sand, and pure sand. The beetles lay their eggs only in moist soil, therefore this factor was constant with all the soils. In this experiment the soils were also placed at a level and on slants.

Eighty per cent of all the eggs were laid in steep clay, and 98 per cent in sloping soil. Thus he concludes that the egg-laying habits of these beetles determine their habitat, for if they could not get the kind of soil and the slope needed, they would not breed. In this case the fluctuation and distribution of a species would be dependent upon a single factor. This may be true in the distribution of a great many plants and animals.

Basic Environments

There are three states of matter, gas, liquid, and solid. These are evident in the land, the water, and the air in which living things are found. Life is only found in conditions where it is at least partially fitted or *adapted* to live. These conditions, called factors of the environment, are air or its contained gases; water or moisture; temperature; light; chemical constituents in soil, water, or foods; gravity; the presence of a substratum on which the organism rests, such as soil, moving objects in the water, or the sea bottom; molar agencies, such as wind, water currents, or any moving force in the environment; and finally, biotic factors which come through the interaction of other organisms in the same environment.



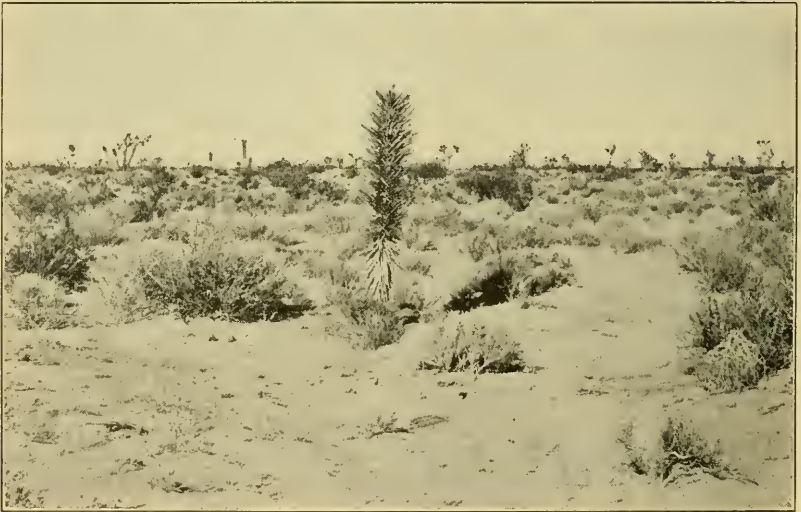
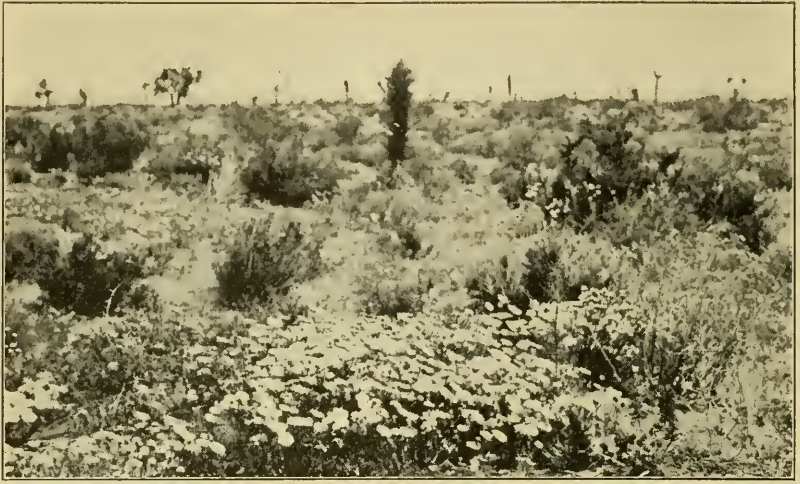
A birch forest is composed of typical mesophytes.

Water as a Factor

Water is absolutely essential to life, from 40 to 95 per cent of all living things being formed of this substance. It is generally true that no growth or life process of either plants or animals can take place without water. An example of this relationship of moisture to life is shown in the story of the British Museum snail related by Mr. Baird.¹

"On the 25th of March 1846 two specimens of *Helix desertorum*, collected by Charles Lamb, Esq., in Egypt some time previously, were fixed upon tablets and placed in the collection among the other Mollusca of the Museum. There they remained fast gummed to the tablet. About the 15th of March 1850, having occasion to examine some shells in the same case, Mr. Baird

¹ *Ann. Mag. Nat. Hist.* (2) vi. (1850). p. 68.

*Wright Pierce*

These photographs were taken from the same spot on the Mohave desert floor. The upper was made at the end of the rainy season, the lower about two months later. What one factor causes this difference?

noticed a recently formed epiphragm over the mouth of one of these snails. On removing the snails from the tablet and placing them in tepid water, one of them came out of its shell, and the next day ate some cabbage leaf. A month or two afterwards it began repairing the lip of its shell, which was broken when it was first affixed to the tablet."

The uses to which water is put by an organism are manifold. It is necessary as a solvent for foods within the body. In living tissue it becomes a medium of exchange between different parts of the body, while in higher animals it carries off body heat, thus helping in the regulation of their temperature. In air it causes humidity. In soil it carries the raw food materials of green plants. In many alkali lakes, such as Great Salt Lake, fish life is practically absent and the numbers of insects and crustaceans inhabiting such water are greatly reduced because of the high mineral content of the water. On the other hand certain crustaceans, such as the brine shrimps, are only found in water containing a high concentration of salts. Acid lakes and streams contain only certain types of fish, and according to investigation by Jewell¹ are lacking in snails, possibly because of the absence of lime from which snails build their shells.

Temperature

Differences in climate (which after all are largely differences in temperature and water supply) are accompanied by changes in the appearance and kinds of plants and animals. The life processes of organisms proceed between certain maximum and minimum limits of temperature. Somewhere between these is an *optimum* temperature at which the life processes function most normally. In plants optimum temperatures vary greatly for different species, and are largely instrumental in determining what plants will grow in a given locality. For example, apple-raising regions must have a mean summer temperature of not more than 70° F. The optimum of most tropical plants ranges over 90° F., while alpine species require a temperature slightly above freezing. The temperature of plants changes rapidly, depending on the amount of external heat they receive. This has an important bearing on horticulture. Lemons on the trees, for example, freeze at a temperature of 28° F., and oranges at 26° F. They are often kept from freezing by means of heaters. Plant injuries caused by freezing are due to the rapid withdrawal of water from the soft parts, therefore plants with a high water content are more easily injured. This accounts for the freezing of the young tips of trees. Seeds which have a small water content are capable of withstanding very low temperatures.

In animals, as in plants, the life processes proceed best at optimum temperatures which differ with the species. Most protozoa divide

¹ Jewell, "The Fishes of an Acid Lake," *Trans. Amer. Mic. Soc.*, Vol. XLIII, 1924, pp. 77-84.



© W. L. Maechttlin

During the freezing weather in January, 1937, in California, citrus groves which were adequately protected by heaters lost relatively little fruit, while many unprotected groves suffered a complete loss of fruit as well as some trees.

much more rapidly at warm than at cold temperatures, and this is true of the reproduction of many animals. Many tropical animals may withstand cold temperatures, but will not propagate at those temperatures. H. B. Ward¹ has made observations on the sockeye salmon which indicate that these fish in swimming up rivers to spawn always take the river of slightly cooler temperature, a difference of 1° F. being sufficient to divert the fish. Seasonal cycles of activity are largely influenced by temperature, this being particularly true of reproductive activity, which plays a part in the migrations of birds, the rapid multiplication of plankton and other forms. Some animals respond to a cold temperature by going into a resting state or *hibernation*, while others go into a dormant condition because of unfavorable conditions of heat and dryness. This latter state, *aestivation*, is often seen in regions having marked periods of alternating rain and drought.

¹ Ward, H. B. "Some Responses of Sockeye Salmon to Environmental Influences during Fresh-water Migration." *Ann. and Mag. of Nat. Hist.*, Vol. VI, pp. 18-36.

Animals are said to be warm-blooded or cold-blooded. The former term means that they have a constant body temperature (*homiothermal*), while the latter means that the body temperature varies with the external temperature (*poikilothermal*). Frogs can often be frozen stiff and, when thawed out gradually, will live. This is true of many animals and is an undoubted adaptation which enables them to withstand great cold. Homiothermal animals, however, are more or less independent of the external temperature because their internal body heat remains at a constant temperature regardless of outside fluctuations.

Animals are divided into two groups depending on whether they can easily stand changes in external temperature, some being restricted to a relatively narrow range of temperature changes (*stenothermal*), while others have not only the ability to withstand a large range of temperature, but also may become acclimated to new temperature ranges if they are changed gradually from one environment to another (*eurythermal*). A classic series of experiments by Dallinger with protozoans showed that he could change their living conditions from 15.6° to 70° C. without having the animals die. It is this ability that gives us the plant and animal populations in some hot springs.

Light as a Factor

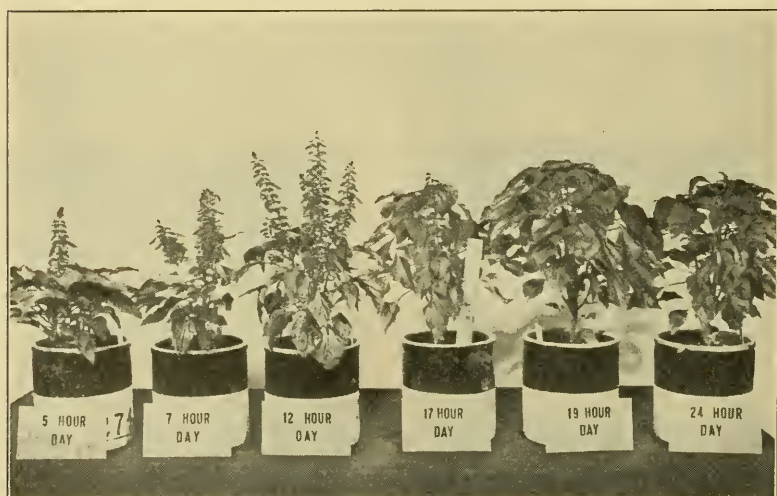
Light is a form of radiant energy. Passed through a prism it is broken up into the primary colors of the spectrum, each of which has



Left : A nasturtium plant exposed to ordinary greenhouse light since germination
Right : Same plant exposed to one-sided illumination for six hours.



Lettuce, a long-day plant.

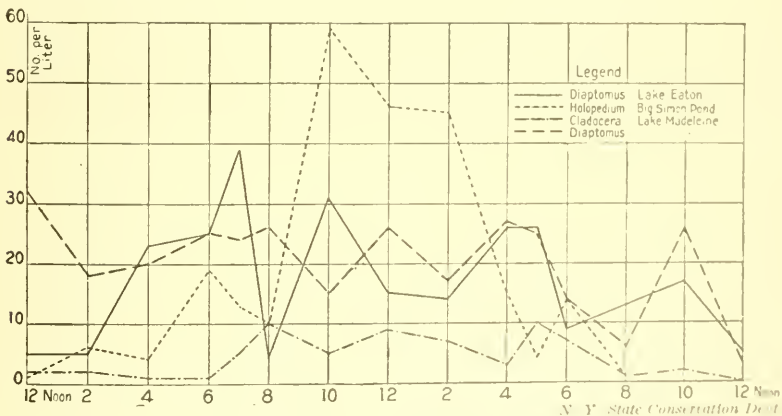


Salvia, a short-day plant. These series of plants were grown experimentally at the Boyce Thompson Institute for Plant Research, Yonkers, N. Y.

a different wave length. In addition there is the non-visible radiant energy of the ultra-spectrum. These different wave lengths have various effects on plants and animals. *Chlorophyll*, the green coloring matter of plants, which depends on the presence of light, absorbs light waves only from the red and blue bands of the spectrum. Whereas most of the radiant energy absorbed by a plant changes to heat, a very small part of it, estimated at not more than 0.5 per cent to 3 per cent, is used by the chlorophyll in the process of starch making. As in the case of temperature, optimum light is necessary for the best work of plants, some preferring shade and others living at their best in bright sunlight.

Light causes movements in leaves and stems as well as changes in the size and shape of these organs. Plants respond to light, the leaves being placed so as to get the most light possible. The amount of light largely determines the shape of the entire plant, trees in a thick forest having a very different shape from similar trees in the open.

The length of daylight has an effect on plants. Some plants, like the radish, spinach, and clover, require a long day to produce flowers and fruit, while fall flowers, such as cosmos, dahlia, and ragweed, require a short day in order to form flowers and fruit. It has been shown experimentally that for each species there appears to be a most favorable length of day for flowering, fruiting, tuber formation, and other food-storing activities. This discovery is of great value to agriculturists.



Curves showing the variation in numbers over a period of 24 hours of several species of plankton organisms from three Adirondack lakes. What factors might be expected to influence their distribution?

Animals definitely respond by movement to the stimulus of light, but unlike green plants, some respond positively and others negatively. The unicellular Ameba is killed by too much light. Earthworms and some other animals are definitely repelled by light. The moth, on the other hand, is attracted to light. Although of great importance, light may be injurious to some forms, for bacteria and some animals are killed by long exposure to it. The dangers from certain wave lengths of light are seen in a bad case of sunburn.

Light influences animals in other ways. Light stimulus coming through the eyes of flounder is said to give rise to changes in the pigment of the skin. Thus the surface of the skin takes on the general color and markings of its background. Some animals in caves lack pigment, and there seems to be a general relationship between light and pigment in the skin. There is a day and night rhythm in the lives of many animals. Land snails feed at night, while activities of most birds are confined to the daytime. Bees go to flowers during daylight. Migrations of plankton are influenced by light, many crustaceans coming to the surface only at night and going deep down into the water during the daytime.



Wright Pierce

A dry alkali lake. Life is practically absent in such areas. Can you explain why this is so?



Fishing boats at the mouth of the Klamath River in northern California. Salmon run in on the outgoing tide apparently in response to the fresh water coming out through the narrow mouth of the river.

Chemical Factors

Under this heading are included all of the chemical factors in the environment of living things. Such are soil, rocks, and the various salts and chemical substances found in food and water. Experimental evidence shows that certain mineral substances are needed for plant growth, and that these minerals are found in the composition of living matter.

Alkali soils form a great problem of agriculture. In sixteen western states this is the greatest problem outside of the water supply. In thirteen irrigated states there is enough alkali present to be harmful to crops. Alkalies are chiefly harmful because their presence causes the soil water to become permeated with these salts, thus hindering absorption of water by the plant.

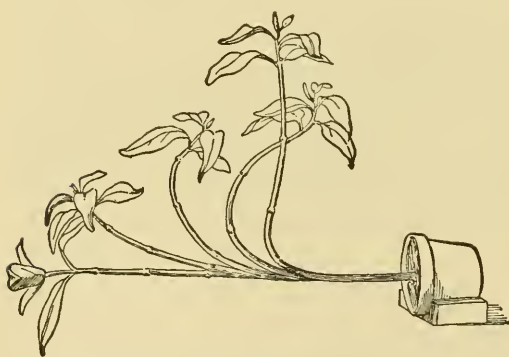
Acidity of the soil is another problem for the agriculturist. It is produced by a number of factors, such as the removal of calcium from the soil, or the production of acids by certain bacteria or from decomposition. Acid affects the plant growth by checking the multiplication of useful bacteria and keeps earthworms and other useful animals out of the soil. However, some species of plants demand acid soils. Mountain laurel, rhododendron, blueberries, and cranberries are examples, as are sphagnum mosses found in certain bogs.

The distribution of fishes and other organisms in water depends largely on whether these waters are neutral, acid, or alkaline. Brook trout, for example, are usually found in acid and neutral waters, while sunfish, bass, perch, and certain other fish are typically associated with alkaline waters.

Carbon dioxide in the atmosphere is another factor which determines plant distribution, three parts to 10,000 being necessary if plants are to make starch. Oxygen is essential for living things. Certain so-called anaerobic bacteria and a few animals appear to be able to live without oxygen. Some insect larvae, worms, and molluscs live a part of the year in deep lakes where little or no free oxygen is present, due to decomposition of the algae. Certainly one factor in the distribution of aquatic animals appears to be the oxygen content of the water.

Gravity as a Factor

The pull we call *gravity* brings about differences in pressure both of air and of water. Plants and animals must adjust themselves to this factor. In a general way gravity determines the size of organisms. Insects and birds which move about swiftly in the air must be small, otherwise gravity would bring them down.



Successive positions, from photographs, showing effect of gravity on a green plant (*Impatiens glanduligera*). — After PFEFFER.

Gravity is important in the growth and orientation of plants. It is a stimulus for the direction taken by the plant body, apparently causing the root to grow downward and the stem to grow upward, while horizontal branches are neutral to the pull of gravity. This same force acts upon sessile or rooted animals, such as hydroids and sponges.

Adaptations to offset the force of gravity are seen in the air spaces of floating plants, oil drops in eggs, spines and long hairs on the surfaces of aquatic plants and animals, and the air spaces in bones and other tissues of birds, and in the construction of feathers.



Meyers

Cypress trees have become adapted to live in swampy lands by developing buttressed bases of the trunks and erect growths (knees) from the roots. These enable the tree to get sufficient air.

Substratum

Anything in which a plant grows or on which an animal comes to rest is known as substratum. Types of soil differ from cold, dense, clayey soils, which though they hold water do not readily give it up to humus that is well aerated, has a high nitrogen content, holds water, and gives it up readily. The distribution of plants depends to a considerable extent on the kind of soil found in a given locality. For example, mosses and ferns grow in moist soil, while cacti are found in sandy desert soils. Varying soil temperatures are brought about by the kind of soil, whether coarse or fine; by the presence of a blanket of living things over it; by its color (dark soils absorb heat more readily than light-colored soils); and by the water it will hold (wet soils are cooler than dry). Great variations occur in the air content of soils and this again determines the plants and animals found in a given area. Water-soaked soil, for example, contains practically no air and does not ordinarily have a large plant or animal population. In some cases a plant adapts itself to water-soaked soil, as seen in the bald cypress.

Animals also differ with different types of soil. This is particularly true of the bottoms of lakes or streams. A different fauna is found on the rocky stream bed from the soft mud of the pool below. Mud contains more food, but it is also more difficult for organisms living in it to carry on respiration. Soil is also the home of such burrowing animals as nematode worms, earthworms, ants, beetles, digger wasps, and the larvae of various insects.

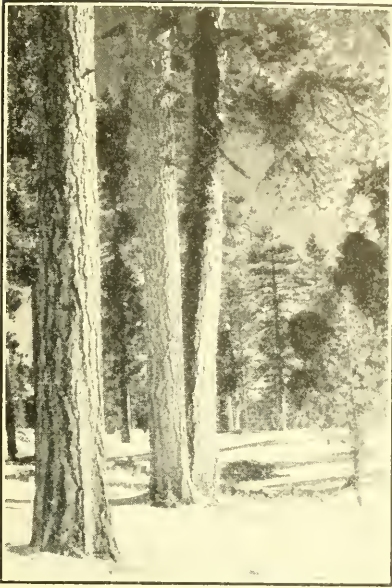
Molar Agencies

Such are any moving agencies. Running water and winds erode; ice moves soil and rocks. Tides cause great differences in aggregations of plant and animal life, animals living between tides having different problems to face from those below the tidal flow. Moving air has a definite effect on vegetation, as is often seen in the wind-blown trees on mountainsides or plains. Moving air acts upon seeds, tumbleweeds, spores, and fruits, thus spreading plants over vast



American Museum of Natural History

Tidal shores, along the New England coast, show wide variations in habitat. The flora and fauna of the intertidal zone differs greatly from that of the regions above and below the tidal flow.



Wright Photo

The effect of differences in environment upon the same species of tree (*Pinus ponderosa*). Here molar agencies are largely responsible for the changed appearance of the tree.

areas, but it also fells much timber, breaks off branches, and destroys crops. Winds may either help or hinder in the migration of insects. The cotton boll weevil travels north more rapidly in the years when more wind is recorded. Winds blow birds and insects out to sea, thus destroying them, or they may land them in a new location where they may multiply rapidly. Currents of air as well as water currents distribute plants and animals. Many animal forms react to wind and water currents. Fish head upstream, an adaptation favorable to food-getting. The swiftness of the current not only determines the distribution of fishes, but also of other forms, such as caddis fly larvae and "water pennies."

Biotic Factors

These are factors arising from the presence of other living organisms. One is concerned when studying ecology not only with the environment of living things but also with how living things react on others in their immediate environment. There is competition not only between plants and animals, but also between plants of the

same and of different species for a place under the sun ; literally *under the sun*, for competition is caused by the limited amount of light that will fall in a given area. Young plants often die because of the shading by the parent plant, and larger plants preempt areas of soil which give little or no space for young growth. Feeding by animals, such



Effect of sheep grazing upon trees. Thousands of young trees are destroyed every year in this way.

as rabbits or sheep, may change the entire flora of a region, while parasitic organisms injure a vast number of the hosts on which they live. There are also marked cases of partnership between organisms, bacteria in the soil giving and taking from both plants and animals, and helping to create a cycle of food substances which pass through the bodies of both animals and plants. The feeding of animals is their biggest business in life, and the presence of a food supply determines very largely the presence of animals in a given locality. It is said that the oak tree serves as food for over 500 species of insects, the apple for 400, clover and corn, over 200 each. Thus man with his tilling of the soil, destruction of the forest, and domestication of plants and animals has changed the fauna and flora of the land.

Having discussed the effects of the *factors* of the environment on living organisms, let us now see how the interaction of these factors affects life in the situations that living things are forced to meet. Animals and plants must be adapted to live either in the water, in air, or on land. The pages that follow show some of these adaptations.

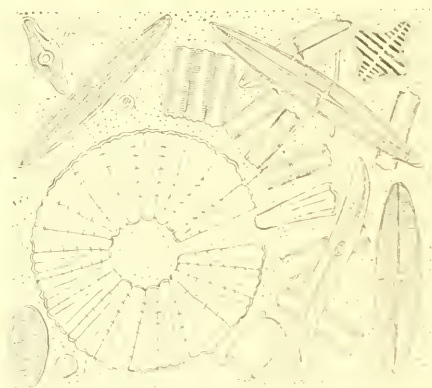
Life in the Water

Plants are adapted for life in water by a much reduced root system, by leaves which either float, are ribbonlike, or are finely divided with air passages and air spaces. The latter spaces help buoy up the plant and also allow for an accumulation of oxygen and carbon dioxide. Green coloring matter is abundant, such plants being better fitted for vegetative propagation than reproduction by flowers and fruits, as is shown by their numerous horizontal and thickened stems. In general, aquatic plants are restricted to relatively shallow water, many species being found floating near the surface.

Animals, usually locomotor and having definite adaptations for movement in the water, have a much wider vertical range. The bodies of most fishes are more or less streamlined, and protected by mucus which covers the backward-pointing scales, their fins being placed where they offer the least possible resistance to the medium. In some animals, the limbs are transformed into flippers, while in lower types, such as protozoa, threads of living matter, *cilia*, are used as whiplike organs of locomotion. Since the oxygen content of water is only about 1 per cent as against over 20 per cent in air, we find special adaptations for taking in oxygen. These structures are usually in the form of gills, delicate structures which will be discussed more fully later.

The water forms an ideal medium for vast numbers of small, free-swimming, or floating organisms, the plankton. Oceans and lakes swarm with them. Every small pool has its plankton, and even rapidly flowing waters will disclose some of these tiny organisms. In certain tested regions in

the Atlantic, plants form about 56 per cent and animals 44 per cent of the total plankton. The flora consists mostly of diatoms, bacteria, and many forms of algae, while the fauna includes numerous dinoflagellates and other one-celled animals, eggs of fish, molluses,



Diatoms have various forms and may be colonial as well as unicellular. There are probably 15,000 species known.

numerous crustaceans mostly copepods, jellyfish, and the larvae of many crustaceans, molluses, and fish. Some of the plankton, such as small crustaceans, tunicates, medusae, small fishes, and larger algae, may be visible to the naked eye, but most of it is microscopic.

	LAKE	PLACID	UPPER SARANAC			MIDDLE SARANAC			LOWER SARANAC				
	DATE DEPTH	JULY 10	AUG 10	SEPT 3	JULY 12	AUG 9	SEPT 4	JULY 11	AUG 9	SEPT 5	JULY 11	AUG 9	SEPT 5
BLUE GREEN ALGAE	1 M												
	BOTTOM												
GREEN ALGAE	1 M												
	BOTTOM												
DIATOMS	1 M												
	BOTTOM												

N. Y. State Conservation Dept.

Comparison of the distribution of *nannoplankton* (minute forms that will pass through the meshes of a plankton net) at the surface and bottom of four Adirondack lakes.

The larger pelagic organisms mostly found in the ocean, such as fish, squid, whales, turtles, and seals, are called collectively *nekton*.

Currents, wind action, the shapes of bays and coasts, migrations of various animals, all cause differences in the horizontal distribution of plankton. Sometimes given forms, as *Cladocera*, will multiply very rapidly, even coloring the water in a large area. The vertical distribution is much more regular with reference to plants, since algae and other green plants depend upon sunlight. Plants get very little light at a depth of 100 meters. At 75 meters' depth, only half as many plants are found as at 50 meters, and careful investigation in various areas shows that most of the plant plankton lives within a few feet of the surface. On the other hand, animals exist at great depths. Beebe reports jellyfish, shrimps, and other plankton at a depth of over 1000 feet and the tunicate, *Salpa*, as well as fishes, at his greatest depth of 3028 feet. Dredgings from the "Challenger" and other expeditions reveal many living organisms, particularly protozoans, in the abysmal depths.

Towing with a plankton net (a thin-meshed net of bolting cloth) near the surface of the ocean on an early summer day would yield a very different distribution of organisms from those collected on a fall or winter day. There is a seasonal variation in distribution. The eggs and larvae of animals are abundant in the spring and early summer, while great numbers of algae appear then which are not found later. This *rhythm* of plant life is believed to be correlated with a turn-over of the available phosphates and nitrates in the water. In the winter, the cooler top layer of water sinks and pushes up the water rich in the salts necessary for plant growth from underneath, so that with the coming of warmer weather the life cycle goes on and a seasonal rhythm of algae appears. This turnover of plant and animal life is very great. The fishing industry on the Grand Banks and in the North Sea is largely due to the occurrence of this great seasonal rhythm of plankton.

There is also a considerable variation in the numbers of plankton near the surface of the water during the day and night. Many crustaceans, for example, come to the surface at night and go down in the daytime, while green algae are usually nearer the surface during the day.

In oceans and lakes, there is a more or less distinct zoning of living forms, depending on the depth of water, the type of shore, or the kind of bottom. A very different fauna and flora exist on a rocky coast from that along a sandy beach. The forms of both plants and animals are different in salt and fresh water areas.

Life in the Air

Here life is more circumscribed. There are no true air plants unless they be the so-called *epiphytes* of the tropical rain forest, some algae, such as the *Pleurococcus* found on the bark of trees, or the lichens, which encrust rocks and tree trunks. The reproductive bodies of plants, such as spores, seeds, and fruits, are furnished with adaptations which enable them to pass long distances through the air, thus allowing new areas to be populated. In animals where locomotion is possible various special adaptations exist. Flying animals have their wings placed where they will not only cause the body to move forward, but also assist in balancing it. Instead of one propeller placed astern, as in fish, flying animals have two paired propellers placed forward at a greater breadth of beam. The body is not only streamlined, but in higher forms special adaptations exist for protec-



Epiphytes in a semitropical forest. Note the aerial roots for securing moisture from the air.

tion against low temperatures and moisture. Oiled skin and feathers of birds are examples. Bones are hollow and large air spaces are found between muscles. In insects a special aerating system exists, since in these heavier-than-air machines a very rapid oxidation of fuel material must take place if the organism is to be efficient in the medium.

Life on the Land

Adaptations in plants for life on the land are seen in the widely branching root systems, the woody stiffened stems, the leaves placed in positions where light may reach them, and in the various adaptive movements which enable green plants to get a share of the much needed light. In tropical rain forests, this relation to light is seen in a vertical zoning where sun plants form long twining stems, making their way up the tall trunks of trees to an upper zone where light is available, while in the lower areas are found shade-loving plants which prefer less sunlight. In animals, where movement is much more evident, there are special adaptations in the form of legs, which support the body off the ground and allow of various types of locomotion such as climbing, crawling, walking, running, and leaping.

Various other types of movement are found as, for example, the waves of muscular contraction in the foot of the slug; the crawling of earthworms where tiny setae are used as levers; the crawling of the snake with its definite use of scales as "ground grippers"; the adaptations for leaping in the grasshopper and the frog; adaptations for climbing, such as the sucking disks on the toes of tree frogs (*Hyla*) and of some lizards, or the arrangement of the toes in climbing birds. These and scores of other adaptations for obtaining food, for breathing, and for protection may be recalled.

SUGGESTIONS FOR FURTHER READING

Borradaile, L. A., *The Animal and Its Environment*, Oxford University Press, London, 1923.

A general book on the natural history of animals.

Elton, C., *Animal Ecology*, The Macmillan Co., 1927. Chs. I, II, III, IV, V.

A fascinating book, written in a charming style. Accurate and authentic.

Jordan, D. S., and Kellogg, V. L., *Animal Life*, D. Appleton & Co., 1900.

Contains some valuable chapters fundamental to an understanding of ecology.

Needham, J. C., and Lloyd, J. T., *The Life of Inland Waters*, Charles C. Thomas, 1930. Chs. III and V.

Interesting aquatic natural history.

Pearse, A. S., *Animal Ecology*, McGraw-Hill Book Co., 1926. Chs. II and III.

Rather technical.

Shelford, V. E., *Animal Communities in Temperate America*, University of Chicago Press, 1913.

A pioneer work, but still reliable and usable.

Shelford, V. E., *Laboratory and Field Ecology*, The Williams & Wilkins Co., 1929.

Very usable for field work.

Weaver, J. E., and Clements, F. E., *Plant Ecology*, McGraw-Hill Book Co., 1929. Chs. IX, X, XI, XII, XIII, XV.

Authentic and well written. It should be of great value in the field.

II

THE BIOLOGICAL CONQUEST OF THE WORLD

PREVIEW. A comparison of two forests · The why of distribution; barriers; successions and their causes; overpopulation and its results · The shifting world of organisms · Ways of locomotion · Adaptability to new conditions · Human interference · Life zones · Life Realms · Suggested readings.

PREVIEW

The science of *Ecology*, or the distribution of animals and plants in a given habitat, was considered in the preceding section. *Chorology* attempts to determine the laws governing the distribution of animals and plants over the surface of the earth.

So long as man accepted the naïve assumption that the earth was originally populated by means of isolated creative acts, there was no point in attempting to explain the distribution of living things. They had all been put arbitrarily in the places where they occurred, and that was all there was to it. With the rise of the belief which culminated in Darwin's famous theory, that dissimilar species have arisen by modification from other species, and that all organisms are related, more or less distantly, to one another, the interpretation of plant and animal distribution became a very interesting and challenging field for study.

How about the varied populations of living things in arctic, temperate, and torrid climates; the absence of animals and plants from areas quite suited to their existence? Why is it that tapirs are found only in South America and the East Indies, while certain fishes, such as the pickerel, occur only in North America and northern Europe? Equally difficult aspects of distribution cropped out, notably in the Australian fauna and flora, which differ so greatly from that of the rest of the world, while most perplexing of all, probably, the habit of migration that makes certain animals, such as birds, seals, salmon, and eels, change residence regularly from one region to another. A gradual suspicion that two environments quite similar in general appearance might nevertheless be populated by species of plants and animals different from each other gave the clue

to a scientific differentiation of specific distribution, *Ecology*, from general distribution, *Chorology*.

A Comparison of Two Forests

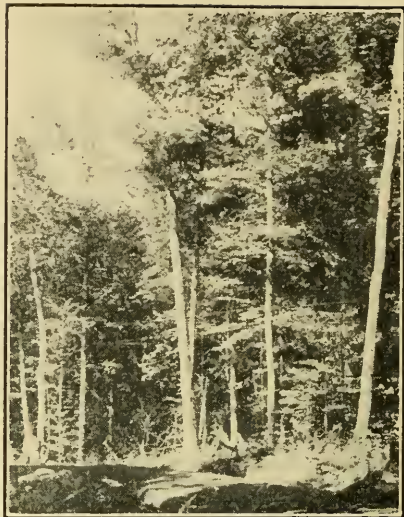
Two writers, Victor E. Shelford, the well-known ecologist, and William Beebe, ornithologist and naturalist, have given two widely different pictures, one, an accurate description of a hard-wood forest in Illinois, and the other, a survey of life in a British Guiana jungle forest.

A typical beech-maple forest, such as Dr. Shelford describes, can be found anywhere in the vicinity of Chicago. Associated with the two dominant trees are ash, elm, walnut, linden, and a wealth of smaller trees and shrubs forming a lower layer under the higher trees. Wild cherry, sassafras, and dogwood are abundant, and in some of the more northern forests, azalea and rhododendron form an intermediate growth. The floor of the forest is covered with herbs and flowering plants, large and small, which change with the season. In spring, trilliums, violets, wild geraniums, anemones, phlox, and scores of other plants are in bloom, succeeded in the fall by asters and other composites, in areas having ample light. A relatively large number of plants having spiny or hooked fruits occur, which aid in their accidental distribution by wandering animals. A few large mammals, deer, fox, and hares, are found occasionally, though are rarely seen. The woodchuck is perhaps the most numerous of the mammals, and the red, gray, and fox squirrels are not uncommon. Of birds the crested flycatcher, wood pewee, blue jay, scarlet tanager, wood thrush, and red-eyed vireo nest in the lower trees, while the oven-bird conceals its curious architecture on the ground. The wood frog, red-backed salamander, and Pickering's tree frog are found, although not always in evidence, and insects abound, especially those that live on trees, such as borers of various sorts, beetles, millipeds, spiders, and insect larvae. Inhabiting the lower layer of the forest are snails, centipedes, sowbugs, and earthworms. This represents, with variations, a typical association of life in a northern deciduous forest.

At first sight the jungle forest does not appear to be very different from the northern forest. Both contain large and small trees, the larger ones in the jungle, such as mora and greatheart, towering to a height of two hundred feet or more, but here the likeness stops. There is an almost complete absence of large horizontal branches in the tropical forest, the trunks of trees shooting straight up for sixty



William Beebe

American Museum of Natural History
Courtesy U. S. Forest Service

A comparison of two widely separated forests. The right-hand photograph is a typical northern mesophyte beech-maple association, the left-hand photograph a tropical rain forest of British Guiana. Note the superficial likenesses and differences.

or seventy feet without a branch, festooned with long climbing lianas, which in this way work from the forest floor into the upper zones. Four general horizontal regions, or zones of life, are distinguishable, namely, the forest floor, the lower jungle up to about twenty feet, the mid-jungle up to seventy feet, and the tree-tops, towering a hundred and fifty or two hundred feet high. Life at first seems almost absent in the jungle to the casual observer, but if one stops, and simply looks, the jungle wakes up and life appears everywhere. The forest floor is covered with the accumulated debris of ages, fallen trees in different stages of decay, fungi, mosses, and lichens, with a generous covering of brown leaves, for here the leaves fall all the year around, instead of only in the autumn season as in northern regions. The ground area is occupied by occasional deer, paca, and tapirs, with agoutis and armadillos found more frequently. Partridge and the strange tropical tinamou are seen here and there, as well as jungle mice and rats, salamanders, frogs, a few snakes, innumerable scorpions, beetles, grubs, worms, and rarely, the unique and interesting *Peripatus*.

In the low jungle are found manikins of several species, ant-birds, with trumpeters and jungle-wrens, while at night opossums climb

about through the underbrush. During the daytime the wonderful morphous butterflies, brilliant spots of blue, add a touch of color to the picture.

The mid-jungle contains the most life. Here innumerable birds, curassows, guans, pigeons, barbets, jacamars, trogons, and smaller feathered species abound, in company with ant-eaters, sloths, squirrels, bats, coatis, and small monkeys such as marmosets.

The upper jungle of the tree-tops is the most difficult region to know. Red howlers and besom monkeys move about in the tree-tops, and occasional glimpses may be had of toucans, macaws, and great flocks of parakeets and parrots that live there. Fierce ants prevent tree-climbing, and the relatively great height and mass of foliage make living things not easily accessible to observers in this upper layer of the tropical rain forest.

These two forests, the northern maple-birch and the jungle, by their entirely dissimilar populations illustrate contrasts that might be found in many parts of the world. Sometimes conditions in widely separated areas may be almost similar, with diverse populations inhabiting them, and again, localities close at hand may show remarkable diversities in their living inhabitants. When regions far apart have similar populations, which does not commonly happen, the biologist is faced by a puzzling problem.

The Why of Distribution

Jordan and Kellogg¹ give three laws to account for the distribution of organisms which they state as follows: Every species is found everywhere that conditions are suitable for it unless (1) it was unable to reach there in the first place, or (2) having reached there it was unable to stay because it could not adapt itself to the new conditions, or (3) having entered the new environment it became modified into another species. It is not only the normal habitat that determines the presence of a given plant or animal, but its accessibility from the place of origin.

Although every species originated *historically* from some preceding species at some definite place, its present distribution results from the working of two opposing factors, expansion and repression. The factors of expansion will be mentioned later. Those of repression are, first, inadequate means of dispersal because slow-moving animals

¹ Jordan, D. S., and Kellogg, V. L., *Animal Life*. Appleton, 1900.

are necessarily limited in their distribution. A second means of repression lies in the poor adaptability of organisms to new localities which they have invaded. A round peg will not fit in a square hole, nor a square peg in a round hole, but if the peg consists of a plastic material it will adapt itself. The normal habitat for a species is the place where the organism is most nearly in physiological equilibrium, the geographic range being determined by the fluctuation of a factor, or factors, which are necessary for the life of a species.

Barriers

Each species widens its range of distribution as far as possible and tries to overcome obstacles which nature has put in its way. These obstacles may be chemico-physical, geographical, or biological barriers.

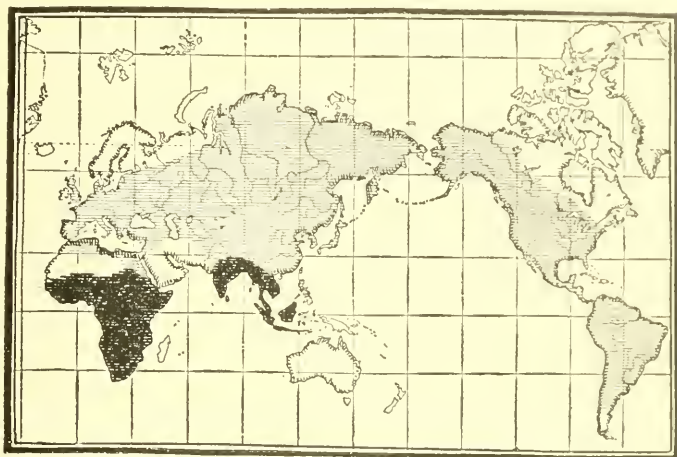
In general chemico-physical barriers are climatic in nature, such as unfavorable conditions of moisture, soil, or temperature. Soil deficiencies, salinity, the presence or absence of light, or character of the surrounding medium might also be mentioned. These climatic



Fraser

Why might such a mountain barrier restrict the distribution of certain plants and animals?

barriers may be in vertical zones, extending from the ocean level to mountain tops, as well as horizontal, spreading out north and south from the equator in zones of latitude.



Map showing ancient and modern ranges of the elephants and their ancestors. The shaded area shows the former habitat of the mammoth and mastodon, ancestor of the modern elephant. A land connection probably existed between Asia and North America. Note the restricted range of the present-day elephants indicated by heavy shading. How can this be accounted for?

Sometimes natural barriers occur, such as high mountain ranges with eternal snow, deserts with unfavorable conditions of moisture, or in the case of water-distributed animals such as fishes, high waterfalls may prevent them from moving up a stream beyond a certain point. The barrier for one organism, however, might be a highway for another. A desert would be an impassable barrier to a squirrel but not to a camel.

Geographical barriers have not always been fixed. Geological history reveals the fact that some land surfaces were once occupied by water and what is now water may have been land. The presence of fossil seashells in the Panama Canal area indicates that the Isthmus was formerly submerged, and there is evidence that as late as Eocene times there was a land connection across Bering Straits. As barriers have changed so has the resulting distribution of organisms. Distribution often indicates the geography of the past. Members of the same genus may differ widely in certain isolated localities, as, for example, the tapirs found in tropical America and the Malay

Peninsula with its adjacent islands. In early geological times members of this genus were widespread and abundant, whereas now, due to the disappearance of former land connections, there are but two widely isolated species in existence.

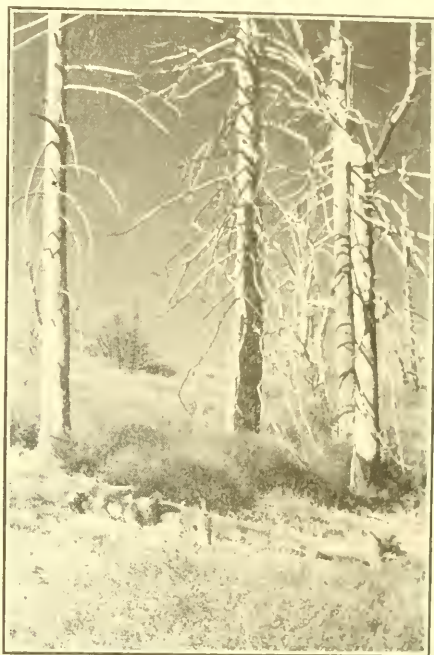
The distribution of animals is bound up in their food supply. Hence carnivorous animals are restricted to areas where the animals on which they prey live. Often a biological barrier is created by the presence of animals which are parasitic on a given form. The tsetse fly, *Glossina*, which frequents the river bottoms and shores of lakes in certain parts of Africa, prevents the ranging of other than native cattle in these areas because of the fact that they transmit a blood parasite fatal to such animals. Man himself is most active in both creating and breaking down barriers. He introduces new animals and plants either purposely or by chance into areas where they thrive and replace other species, or by building dams, irrigating, deforestation, or accidentally burning over areas, he destroys one kind of life perhaps never to replace it with another.

Successions and Their Causes

Succession means that in a given area organisms succeed one another because of changes in the environment, migration taking place so that they may reach conditions favorable to their development. An example of plant succession may be seen in almost any pond that is gradually drying up. In deep water there are a few submerged aquatic plants; in water from 6 to 8 feet deep floating plants such as pond lilies are found; in shallow water from 1 to 4 feet deep, cat-tails and reeds are abundant; while at the edge we find a meadow of sedges and some bushy plants. As the pond becomes drier, these plants slowly push outward until eventually it may be completely filled with plants which build up soil, making first a swamp and eventually a meadow, while around the edge of the former pond will now be a forest of trees and bushes. In the tropical oceans different corals succeed each other, growing on the skeletons of other species, thus building their way into shallow and warmer water, or along the ocean shore colonial diatoms may occur, to be followed by hydroids and seaweeds, the latter becoming a dominant *climax formation*, a group of species that are better fitted to survive in that habitat than any others.

Erosion, which carries away the original inhabitants, or a deposit of new soil by running water, wind, or other agencies, gives opportunity for the establishment of new life in a region thus devastated.

The question of how long seeds will survive, under what conditions they will germinate, and how fast they will grow is of great importance in the repopulation of areas after soil erosion or fire. Beale reports an experiment where ten out of twenty-two species of seeds sprouted after having been buried in open bottles in moist sand at a depth of three feet for over forty years. After a coniferous forest has been devastated by fire, an entirely new series of plants spring up in the area; first herbs, such as fireweed or wild mustard; then trees or bushes, the seeds of which may be brought by birds, as raspberry, blackberry, or wild cherry; later a stage of trees having wind-blown or bird-carried seeds, such as aspen, cottonwoods, or birches. Still later the forest may become repopled by its original inhabitants, which becomes the climax.

*Wright Pierce*

A typical undergrowth succession after a forest fire.

Conditions of wind, moisture, sunlight, and weather, the sum total of which constitutes climate, play a most important part in succession. If drought destroys life in a given region, an entirely new group of plants may come to occupy that area, bringing with them a new group of animals. Migrations of animals may be brought about by changing seasons.

The biotic conditions governing successions are many. Man, through clearing forests, throwing wastes into rivers, or introducing new plants or animals which may compete with existing species, often completely upsets the balance of life and causes successions. Industrial pollution may completely depopulate streams of fish life, bacterial growth replacing the original plants and animals. Sometimes new organisms add so many competing mouths to feed in a given territory that it becomes necessary for some to break away if any are to live.

Overpopulation and Its Results

One of the factors in determining the spread and distribution of organisms is overpopulation. An annual plant, for example, producing only *two seeds a year*, which is far below the actual number, and always developing these into mature plants, in only twenty-one years would have 1,048,576 descendants. A pair of common houseflies which usually produces eggs six times a year, each batch containing 150 to 200 eggs, with the young flies beginning in turn to lay eggs in about fourteen days after hatching and repeating the life cycle, might, it is calculated, beginning to breed in April, if all the eggs were hatched and no individuals died, give rise to 191,010,000,000,000,000,000 descendants by the end of August. However, each species, year in and year out, tends to remain about stationary in number. Indeed, many species are actually disappearing. The reasons for this check of potential populations are found in lack of adequate food supply, lack of favorable breeding conditions, and in the fact that many animals and plants become food for others.

The Shifting World of Organisms

There is no doubt that *desire for food* furnishes the greatest urge to locomotion and exploration in animals. Dr. Crothers once said in one of his essays that the "haps and mis-haps of the hungry make up natural history." Indirectly there is the same necessity for food on the part of plants, but here the urge is expressed not so much in locomotion as in a struggle for position with reference to light, which is essential to every green plant in the manufacture of its own food.

Changing environmental conditions may force the movements of organisms and produce faunal and floral repopulations. For example, it is known that drifting coconuts frequently float long distances and grow into trees upon some distant shore. A recent cataclysm of nature has given us an opportunity to see the repopulation of a devastated area taking place. In 1883, the volcanic island of Krakatao was literally blown to pieces by a series of terrific explosions that destroyed every living thing on the island. Less than three years after the volcano became quiescent, a Dutch botanist visiting the island found the ash which covered its surface completely carpeted with a layer of bacteria, diatoms, and primitive blue-green algae. Here and there ferns were found, along with several kinds of mosses. There were even a few flowering plants, but no trees or shrubs. In

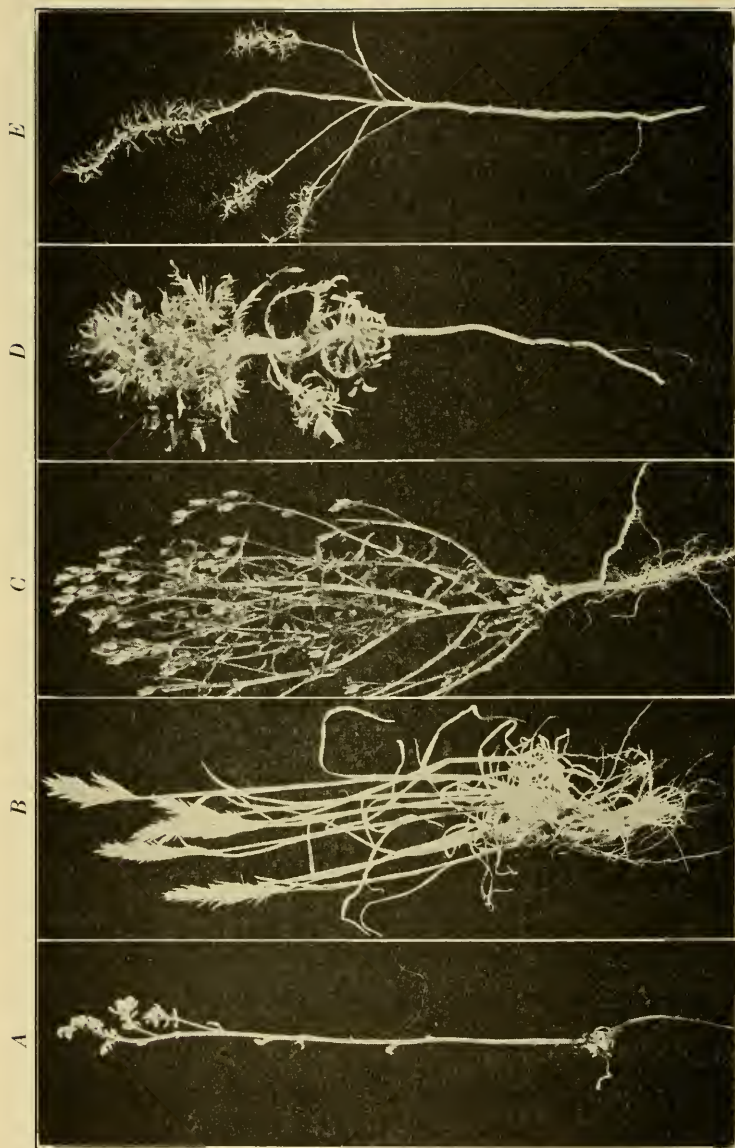
that short time, the naked land had been partially repopulated with these several low forms of life, by spores or seeds blown through the air, or floated in water from the nearest islands, which were about fifteen miles away. Twenty-three years after the explosion, Professor Ernst visited Krakatao and reported a forest of coconut palms and figs growing near the shore line, a luxuriant jungle in the interior, and considerable animal life, represented by species that could either fly or drift to the island on floating wood. Ernst estimated that within another fifty years this island would differ in no respect from its neighbors, a prediction, however, which seems doomed to failure of confirmation because the volcano has again gone on a rampage.

Variations in temperature, brought about by the changing seasons, are a factor in the movements of animals. This is particularly true in the case of the annual migrations of such animals as crabs, lobsters, and squid, which go into deep water in winter, returning to shallow shore-water in spring. Movements apparently dependent to some extent upon temperature occur in the case of many marine fishes, and birds, certain butterflies, and bats, that go north and south according to the season. Many animals move up and down mountain slopes probably for the same reason.

Sometimes other factors than scarcity of food, environmental changes, or seasonal differences cause migration. Lemmings, for instance, small rodents living in the mountainous districts of Scandinavia, at intervals of from five to twenty years suddenly move forth in vast numbers, with no apparent Pied Piper of Hamelin to lead them, but always in the same general direction, swimming rivers and lakes, overcoming all sorts of obstacles, and eventually ending the mysterious trek in the ocean. Although they feed on the way and consume enormous amounts of food material, the search for food is not sufficient to explain their fatal pilgrimages.

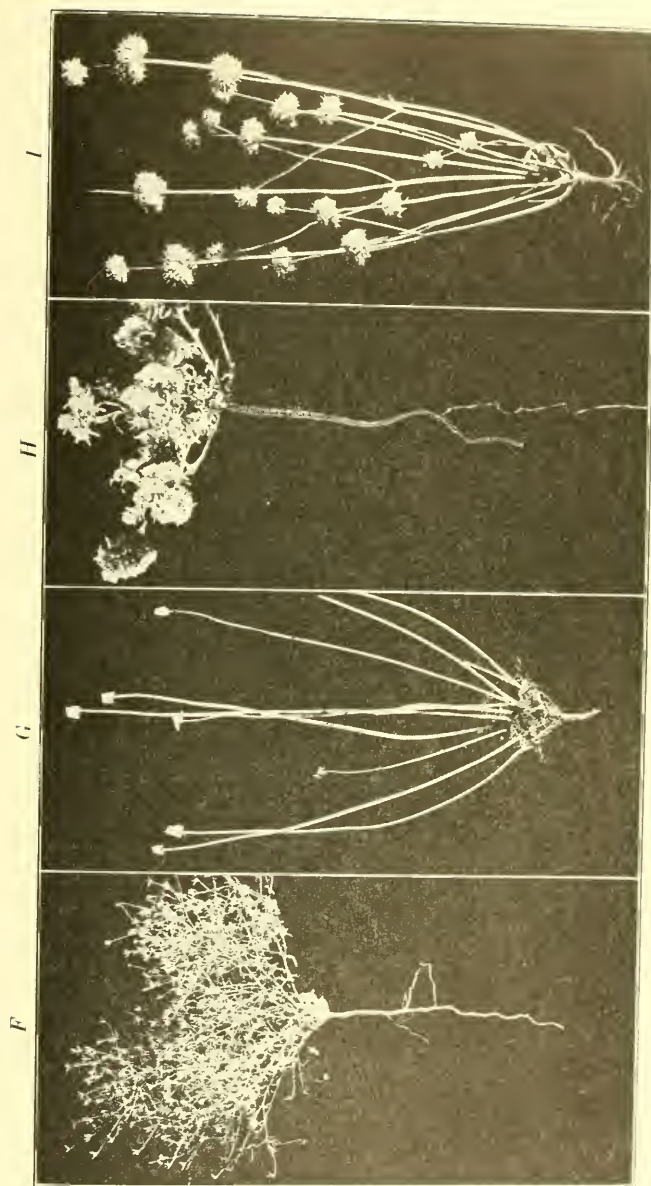
The relation of different degrees of salinity to the breeding habits of food-fishes probably influences their distribution also, by determining the character of organisms in their feeding grounds. Pettersson found that herring only enter the Baltic when the salinity gets to a certain degree, whereas Galtsoff found that in America the migration of mackerel is due not so much to salinity as to temperature. Thus, different factors appear to influence different species in determining their movements.

Birds, because of their ability to fly, are better able to seek out a favorable place for abode than most animals. Many different reasons



Wright Pierce

A, *Lepidium* sp.; B, *Hilaria regia* (galleta grass); C, *Gilia* sp.; D, *Gilia Matthaei*; E, *Oenothera decoriflora* var. *deserlorum*.



F. Lessingia sp.; *G. Plantago* sp.; *H. Lepidium* sp.; *I. Salvia columbariae*.

The above plants form part of the desert flora. Note the long taproots which enable the plants to get water, the dwarfing or almost total absence of leaves, and the adaptations for scattering seeds.

Wright Press

have been given to account for the long-distance migrations of ducks, geese, the Arctic tern, golden plover, and other remarkable feathered travelers. Food cannot be the deciding factor, because many birds leave for the south while food is still abundant. Neither can tempera-



The annual migration routes of the Arctic tern. It covers about 22,000 miles in its yearly round trip from its winter range in the Antarctic to the summer breeding range in the Arctic. Note the different routes taken going and coming.

ture be the only cause, because a majority of migrating birds go south when the weather is still warm, while robins and other birds often stay behind and winter successfully in cold climates. Humidity, atmospheric pressure, winds, have all been considered as playing a part in migration, but it is more likely that something within the bird rather than any external environmental factor is the impelling cause for this impressive phenomenon. For instance, among the hormones produced by the ductless glands, are sex hormones which may stimulate the bird to the extraordinary activity that results in long migratory flights. How to account for the direction and exactness of these migratory flights is another matter, even more difficult to explain.

Changing climatic conditions probably influence plants more directly than animals, because the latter are more capable of move-

ment, and, consequently, better able to escape from unfavorable surroundings. Nevertheless, living things make up a world of shifting organisms, always on the move.

Ways of Locomotion

Much of the delight that the naturalist experiences comes from observing and interpreting the ways and devices by which the movements of organisms are brought about.



Wright Pierce

The Russian thistle (*Salsola*) introduced into this country in 1871. Today it covers the entire country. What adaptations have enabled this pest to do this?

In the world of attached animals, like sea-anemones and corals, that apparently are doomed to remain in one place, the free-swimming larvae seize the opportunity to break away from the maternal apron-strings before settling down for life, just as stationary plants by means of spores, seeds, and climbing or trailing vegetative parts are enabled to shift about and occupy new territory. Seeds of orchids and certain spores of fungi, mosses, and ferns, for example, are light as dust and may be wafted hundreds of miles in the air before settling down to germinate on some distant soil. Seeds of dandelions and other plants, such as milkweed, willow, and cottonwood, have feathery parachute-like structures, which support them in the air for some time, even in a wind blowing only two miles an hour. Insects, ballooning spiders, and birds make use of air currents, sometimes being carried long distances, particularly by heavy winds. Whole plants, like the Russian thistle, and the "resurrection plants" of desert regions, may dry up and break loose from their anchoring roots, and roll along the ground or ride the breeze scattering their seeds, thus taking root in newly invaded regions.

ESTIMATE OF SEEDS PRODUCED BY A SINGLE LARGE WEED

Dandelion	1,700	Crabgrass	89,600
Cockle-bur	9,700	Russian thistle	150,000
Oxeye daisy	9,750	Pigweed	305,000
Prickly lettuce	10,000	Purslane (large)	1,250,000
Beggar's ticks	10,500	Tumble mustard	1,500,000
Ragweed	23,000	Lamb's-quarters	1,600,000

Some fruits, like those of violets and the witch-hazel, explode, sending their seeds to a distance. Even gravity may sometimes be responsible for spreading plants by means of soil-slides, while animals in such accidentally disturbed soil may be carried considerable distances to a new situation.

Birds inadvertently scatter fruits and seeds by first swallowing and then depositing them elsewhere with their droppings. As a result cherry bushes and poison-ivy vines may often be seen growing along fences where birds have roosted.

Adaptability to New Conditions

The fact that some organisms do not invariably adapt themselves to new localities which they have invaded is a great deterrent to their permanent spread. Successful invaders that gain a new foothold as pioneers, and retain it as settlers, are conspicuous enough to be discovered and remembered, but unsuccessful ones, reaching the Promised Land but unable to establish themselves there, escape attention. Indian corn, for example, seems unable to reproduce and maintain itself if allowed to run wild. The yellow-fever mosquito has a certain dead-line, north of which it cannot successfully continue to live.

Just as in economic life, so in communities of plants and animals, undesirable individuals frequently appear, bumming their way into places where they are not wanted. Weeds are notorious plant-hoboes that are pre-eminently successful on their own part, but are unwanted by man, and reckoned as outlaws with a bad reputation, because they rob other plants which man favors, of food, moisture, and sunlight. Having great natural vitality, they are successful because they usually grow even in unfavorable conditions which would kill competing plants, and produce enormous numbers of seed. Their persistence and varied means of seed dispersal are easily realized by anyone who has tried to pick "beggar's ticks," and "sticktight's," and burrs from his clothes after a ramble in the autumn woods.

Human Interference

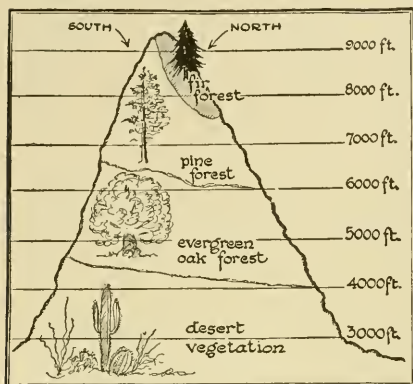
Man is often the unwitting cause of shifts, sometimes with serious results, of animal and plant populations. The Russian thistle, already mentioned, was introduced into South Dakota in 1874 with flax-seed from Europe. By 1888, it was reported as a troublesome weed in both the Dakotas. By 1898, it had covered all the area east of the Rocky Mountains from the Gulf of Saskatchewan, and today ranges over the whole country.

There are many curious cases of the accidental transport by human agency of animals and plants to regions far from their point of origin. Recently a tropical boa landed in Middletown, Connecticut, with a bunch of bananas. Tropical tarantulas, too, are known to be carried over long distances in the shipment of this fruit. Such instances as these, however, usually have no lasting effect on the general spread of organisms, yet they emphasize the fact that unanticipated developments in distribution are quite possible from very insignificant and unsuspected beginnings. Man's interferences with the distribution of organisms have by no means always been unfortunate or disastrous. In many instances his rearrangements of plant and animal populations have been eminently successful. The planting of various species of trout in new streams has proved to be a wise move, while the introduction of reindeer into Alaska and Labrador is of incalculable benefit to both man and beast. The list of cases where man has lifted the lid of Pandora's box and set free plants and animals for weal or woe into new localities could be extended indefinitely.

Life Zones

Reference has already been made to a zonal distribution of plants and animals in a pond. A similar condition is easily seen in climbing any high mountain. Life zones are often rather sharply marked, but usually show transitional areas between them. A region which has been carefully studied and which shows this zonal distribution in a marked way is the San Francisco mountain region in north Arizona. Here, a mountain nearly 13,000 feet in height rises out of a desert plain. This mountain shows successively two types of desert zone, a lower and upper, each with its own desert fauna and flora, cacti, sagebrush, a few birds, mice, lizards, and snakes. Then a region at between 6000 and 7000 feet of piñon pines and red cedars, inhabited by more birds and a small number of mammals. Between 7000 and

8200 feet there are forests of Douglas and balsam fir, with such mammals as meadow mice, chipmunks, deer, lynx, and puma. Higher still, between 8200 and 9500 feet, is a typical Canadian vegetation, timber



Zonal distribution of flora on a mountain peak rising from a desert area. How would you account for these different life zones?

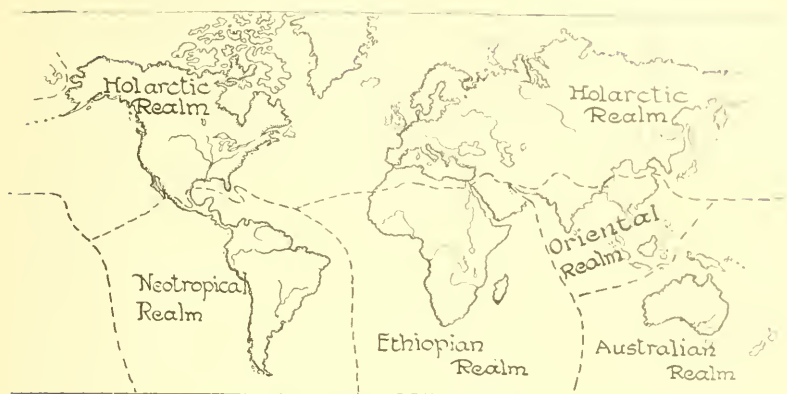
pine, Douglas and balsam fir, and aspens, while the woodchuck, porcupine, rabbit, marten, fox, wolf, and other northern forms are found. From 9500 to 11,500 feet we find a fauna and flora almost like that of northern Canada and called Hudsonian. Stunted spruce and pine exist up to the timber line with a few typical mountain mammals such as the marmot, and pika or mountain hare. Above this area lies the rocky Alpine zone, snow-clad for half the year even in this warm, sunny climate.

Lichens on the rocks and a few stunted herbs are the only plant life visible, while a limited number of insects and an occasional mammal from the Hudsonian zone are the only signs of animal life.

The facts that the chorologist has discovered concerning life zones have been put to practical use by the Biological Survey of the United States Department of Agriculture. A life zone map has been prepared so that the settler going into a new region will know at once the kind of plants and animals best adapted to live there. In addition, information is available about the character of the soil, the rainfall, temperature range, and the particular cereals, fruits, and vegetables that can be grown in the region.

Life Realms

Different parts of the world, each with its several life zones, have been separated into life regions, or realms. If we plot the distribution of a given family of animals or plants, we often find that species within the group have a wide distribution, in some instances covering more than a single continent. Australia has long been set aside as a distinct realm because its peculiar fauna and flora differ from those in other parts of the earth and so is called the Australian Realm.



Map showing life realms.

Similarly there are the South American, or Neotropical, Ethiopian, Oriental, and Holarctic realms, the latter comprising most of the land surface of the Tropic of Cancer. Each of these regions has animals and plants peculiar to itself, although resemblances are often found between inhabitants in different realms.

SUGGESTED READINGS

Beebe, C. W., Hartley, G., Howes, P. G., *Tropical Wild Life in British Guiana*, New York Zool. Soc., 1917. Ch. VI.

Contains an interesting description of a tropical rain-forest.

Borradaile, L. A., *The Animal and Its Environment*, Oxford University Press, London, 1923. Chs. VII, VIII, X, XI, XIII.

Excellent for general reading.

Elton, C., *Animal Ecology*, The Macmillan Co., 1927. Chs. III, V, X.

Fascinating reading.

Jordan, D. S., Kellogg, V. L., and Heath, H., *Animals*, D. Appleton & Co., 1909. Chs. VII, XVI.

Old but reliable.

Pearse, A. S., *Animal Ecology*, McGraw-Hill Book Co., 1926. Ch. IV.

Rather a book of reference than a reading book.

Roule, L., *Fishes, Their Journeys and Migrations*, W. W. Norton & Co., 1933.

All of this book makes interesting reading.

Walter, H. E., *Biology of the Vertebrates*, The Macmillan Co., 1928. Ch. III.

Interesting and reliable.

Weaver, J. E., and Clements, F. E., *Plant Ecology*, McGraw-Hill Book Co., 1929. Chs. IV, V, VII, XVIII.

Very scientific and yet interesting.

III

THE INTERDEPENDENCE OF LIVING THINGS — THE WEB OF LIFE

PREVIEW. Relations between members of the same species; care of eggs by parents; care of young · Relations of mutual aid · Animal cannibalism · Relations of competition · Relation of members of different species · Adaptations for food-getting in animals · Scavengers · Food-getting in plants; carnivorous plants · Symbiosis · Commensalism · Parasitism · The chemical relationship of plants and animals · Life habits of bacteria · Relation of bacteria to free nitrogen · Rotation of crops · The relations between insects and flowers · Suggested readings.

PREVIEW

Those who have been fortunate enough to be in California or Florida when the oranges are in bloom will never forget their odor; nor will they, when examining the grove, fail to notice the large number of bees visiting the flowers. The bees are after nectar and pollen, yet without these winged agents, the crop of oranges for the following year would probably be small. This interrelationship between insects and flowers was noticed by Charles Darwin, who pointed out that the size of the clover crop in England depended upon the number of cats in a given region. His friend Huxley, who knew better than Darwin how to popularize science, immediately went him one better and added that the size of the clover crop depended upon the number of old maids. When asked to explain, he gave this logical sequence of events. Old maids keep cats; cats prey upon field mice; mice provide nesting places for bumblebees; bumblebees pollinate clover, upon which pollination the next year's crop depends. So he had a perfectly logical chain of events. Throughout nature there is this give and take between different organisms which we call the web of life. When man interrupts or displaces a link in the chain of interrelationships, the web is broken and the whole fauna or flora of a region may be changed, as in the case of the Englishman who took a bit of water cress to Australia, planting some in a nearby stream to remind him of home. This foreign plant, having no enemies and finding conditions favorable for its growth, literally overran the waterways until today the rivers of Australia are choked with water cress. Look-

ing over the world of plants and animals an unescapable dependence of one form of life upon another is found in the food relationship by which green plants supply animals with food and in the shelter relationship, by which animals find safety in the protection given by plants. Reducing this search for food and shelter to its ultimate, we find that all animals are dependent upon green plants.

But does the green plant get anything from the animal? At first sight it would seem as though it were all give and no take. As we study the situation more closely, however, we find that food-making is dependent upon certain raw materials, some of which, such as nitrogenous wastes, can only be supplied from the dead bodies of organisms or their excreta. Moreover, another important raw material, carbon dioxide, used by green plants in starch-making, is given off as a respiratory by-product by animals, and in this same process oxygen is released.

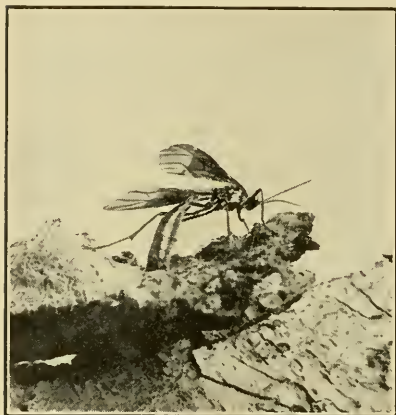
All of these facts suggest certain problems. Why, for example, when some animals produce enormous numbers of eggs and others only a few, do not the former outnumber the latter? Of what significance is the mutual aid so frequently observed in nature? What is symbiosis and why is it significant? What is the value of pollination by insects as compared with pollination by other means? What part do bacteria play in the lives of plants and animals? What is the reason for parasitism? Can the oft-repeated statement that green plants make food for the world be proved? A start on the answers to some of these questions will be made in the pages that follow.

Relations between Members of the Same Species

Many examples of helpful relationships can be seen between animals of the same species, especially in the care of young. Although in low forms, such as sponges, coelenterates, echinoderms, and a good many fishes, large numbers of eggs are laid and given little or no parental care, the production by the male of immense numbers of sperm cells in the vicinity of the eggs insures chance fertilization and continuity of the species. For example, Norman¹ reports that a eel which weighed $21\frac{1}{2}$ pounds produced over 6,650,000 eggs. At the time of egg laying each male of the above species throws billions of sperm cells into the water near the eggs. Higher in the animal scale we find greater provision for care of the young correlated with a reduction in the number of eggs laid. Many insects lay their eggs on

¹ Norman, J. R., *A History of Fishes*. Stokes, 1931.

plants which will become food for the larvae or caterpillars. Others lay their eggs either in the ground where they are protected, or in



Brownell

Ichneumon fly (*Ophion macrurum*) laying eggs in the cocoon of a Cecropia moth.

dead bodies of animals on which the larvae may feed, as in the case of certain beetles, or in a ball of dung, as in the case of the dung beetle. Certain ichneumon flies bore deep into tree trunks in order to lay their eggs in the larvae of wood-boring insects. Some wasps paralyze caterpillars or spiders, laying eggs in the still living victim so that when the eggs hatch the young larvae will have food. In many animals, food is provided in the yolk of the egg, the eggs of fish and birds being examples. Spiders and earthworms form cocoons, which in the case of the

earthworm are usually filled with a nutritive fluid on which the young feed after they are hatched, while in the cocoon of the spider the young feed upon each other, the strongest of the group surviving.

Care of Eggs by Parents

Some of us as youngsters have angled for sunfish and will always remember the thrill that came when a brightly colored male dashed at the bait dangled over the hollowed nest containing eggs which he was guarding. From the simple nest of sunfish and salmon through the more complicated nests of the stickleback or lake catfish we come to the more elaborate nesting habits of birds. Some birds, as terns, sandpipers, or gulls, simply make shallow holes in the sand, as does the sand ostrich. Grebes and rails make nests of floating decaying vegetation. Nuthatches and woodpeckers make nests in holes in trees where the young are protected. At the top of the ladder are more elaborate nests such as those of the oriole and oven-bird of our latitude or the tailor bird and weaver bird of the tropics.

Care of Young

Sir Arthur Newsholme has said that the most dangerous work in the world is that of being a baby. If the young of plants and ani-



N. Y. State Conservation Dept

Stickleback and nest. Of what advantage would this be to the species?

mals survive this dangerous stage, their chances of growing to adults are very considerable. Although parental care is not associated with plants, nevertheless in low forms of plant life locomotor stages occur, called *zoospores* or *swarm spores*, by means of which the plants gain footholds in new areas. Many devices have already been mentioned by means of which seeds are scattered far from the parent plant. In higher plants, hard shells, spiny coverings, or inedible pulp protect seeds within the mature fruit, thus giving greater opportunity for the scattering and germination of seeds.

Adaptations for the protection of young are more evident among animals. In crustaceans, the larvae of which form the chief food for great numbers of fish, there are not a few protective adaptations. In some instances crustaceans have brood pouches in which the young are kept, or, as in the case of crayfish and lobster, the developing eggs are cemented to the abdominal appendages of the mother and carried around by her. The male bullhead swims around with and broods over his young, while the male sea horse has a brood pouch in which the young are held. In some worms and crustaceans, the eggs may be retained in the burrow of the parent, or they may be held in the mantle cavity or a space similar to it, as in the fresh-water mussels, barnacles, and tunicates. Some spiders, notably the wolf spiders, carry the egg cocoon about with them and when the young are hatched, they are carried on the backs and legs of the female

until large enough to care for themselves. The male of the so-called midwife toad (*Alytes*) carries the eggs entangled around the legs. The male Surinam toad places the eggs on the back of the female, where each sinks into a tiny pouch as it develops.

Animals that lay eggs which hatch outside of the mother's body are said to be *oviparous*. A modified form of this procedure is seen



Hugh Spencer

A spider with its egg cocoon.

in some nematodes, arthropods, fish, amphibia, and reptiles. Here the eggs remain in the oviduct or uterus of the mother until they are almost ready to hatch, the body of the mother acting as an incubator. Such forms are said to be *ovoviparous*. Most of the mammals which retain the eggs in the body until the young are born are said to be *viviparous*. Here the young are held as *embryos* within the body of the mother

and nourished by means of an organ called the *placenta*. The young of mammals are suckled at the breasts of the mother until they are able to eat solid food.

Relations of Mutual Aid

A certain amount of protection is afforded plants from their habit of living in communities. Examples are the aggregations of cacti in our western deserts or the acacia and "thorn bush" communities of Australia. The animal world, too, shows many examples of protection among gregarious forms. The schooling of fishes not only is a defense for the group from larger fish, but it also enables small fish, working concertedly, to prey on organisms much larger than themselves. The driver ants in Africa, traveling in great swarms, often overcome and devour animals hundreds of times larger than themselves. Wolves hunt in packs, several of them rushing together to bring down their larger prey. Deer and other herbivorous animals move in herds for mutual protection.

Another relation of mutual aid results from the development of division of labor among certain animals. Although social division of labor is well seen in the human species, there are many examples in the insect world, particularly among the social bees and wasps,

such as the division of the colony into castes that include males (drones), fertile females (queens), and infertile females (workers). Castes are even more numerous among ants, there being winged and wingless females, intermediates between females and workers, soldiers, several groups of workers, and winged and wingless males. Not all of these forms, however, are found in any one species. By means of such division of labor, life in the colony goes on at a very efficient level.

Animal Cannibalism

Most of us have had the experience of having some pet destroy her young when they were in danger, or of having laboratory-bred rats or mice eat their newborn young. This is probably a perverted instinct, but nevertheless animal cannibalism is seen rather frequently. The destruction of a wounded member of a pack of wolves when hunting is usual. The female spider usually kills the male after fertilization of the eggs, this habit being common to some other forms. Similarly the eggs may be destroyed by the male, as in the case of the mole cricket and centipede, which eat the eggs shortly after they are laid, the mothers resorting to numerous protective devices in order to thwart the cannibalistic fathers. Many fish eat the eggs of their own species. Even the domestic hen at times will eat her own eggs.

Relations of Competition

Evidences of competition in the plant world are numerous. Because of their sessile habit, older plants may overshadow and crowd out the young ones, or one group of plants may prevent the growth of other plants in the vicinity. Weeds and plants in general produce enormous quantities of seed, which are kept from germinating by the rapid growth of the older plants. Many grasses and some shrubs grow rapidly by means of underground shoots, in this way securing territory which might be used by other plants. Thus plants with favorable adaptations may completely pre-empt new territory for themselves at the expense of others less able to use the environment.

In animals, competition between individuals of a species is almost universal. Males fight each other for the possession of females, or sometimes just for the sake of fighting. There is a continual struggle for food, for water, and for a place to live. Larger animals, as we have seen, prey on smaller ones and in general those best fitted to compete in the battle of life survive.



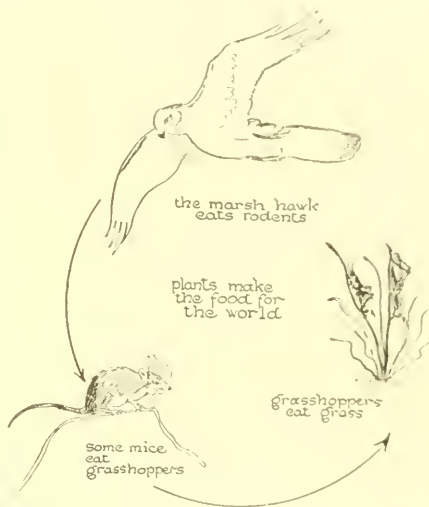
Wright Pierce

This desert weed, rabbit brush (*Chrysothamnus nauseosus*) has pre-empted newly cleared areas along the border of the Mohave Desert. How would you account for its rapid spread?

Relation of Members of Different Species

No one who has carefully watched the life that goes on in a grove or forest can escape seeing there the enactment of a drama that represents the larger picture of relationships between living things the world over. Insects are flying through the air, crawling along the ground, or burrowing into decaying logs and the ground. Spiders and ground beetles may occasionally be observed making off with a victim, while here and there birds such as woodpeckers, flycatchers, and warblers may be seen feeding on adult insects or their larvae, while a hawk may be watching to pounce upon some one of the insect-eating birds. If we were able to make a prolonged study of the area we would find that squirrels, rabbits, and wood mice are food for larger flesh-eating animals or carnivores, such as foxes. In such an area we might also find a series of herbivorous animals ranging from plant lice (aphids) living on the leaves of trees to occasional deer which browse on the leaves of the same plants.

It will be noted in the illustrations given that animals almost invariably feed upon others smaller than themselves. The same relationship is seen in lakes or oceans where microscopic plants and animals (plankton) form the food of other larger organisms, especially fish. These living things form definite "food chains" in which larger animals feed on smaller and smaller ones until ultimately the lowest forms subsist on tiny green plants or bacteria. For example, in a small pond we may find billions of diatoms, unicellular algae, and protozoa and feeding on them millions of small crustaceans. With them are thousands of insect larvae, hundreds of small fish, and a few large fish, such as bass, pickerel, or perch, which are dependent upon all the other forms of life. In this case a few large animals are dependent for food upon the development of myriads of smaller organisms, the basis of this food being very simple plants. Take away any link in the food chain and life in the pond becomes disorganized, with the ensuing death of many of the inhabitants.



Why will a break in the food chain often cause disorganization of life in that locality?

Since smaller animals reproduce more rapidly than larger ones, the food supply for those "on the top of the heap" remains fairly constant. It should be borne in mind, however, that the larger animals require a range of sufficient size to support them.

Adaptations for Food-getting in Animals

Protozoans, if ameboid, engulf their food, but in other members of this group, food passes into the cell through a definite opening or through the plasma membrane. Sponges and many molluscs pick up microscopic food as it comes to them in water currents. Some molluscs bore holes through the hard shells of bivalves, in that way securing the soft parts of the animal for food. Insects have biting, chewing, or sucking mouthparts, each type being fitted to utilize a



Wright Pierce

Adaptations of beaks of birds for food-getting.

different kind of food. *Carnivorous* mammals have sharp teeth fitted for tearing and holding prey; *herbivorous* mammals have flat, corrugated teeth; rodents, gnawing or chisel-like teeth; while snakes, which swallow their prey whole, have pointed, needlelike teeth to hold their food securely. More striking adaptations for food-getting are found in birds whose beaks and feet both give clues to their food habits. The flesh-eating birds have hooked beaks and curved claws; aquatic birds have feet shaped like paddles and scooplike bills for straining out small organisms from the water; wading birds display a remarkable variety of highly specialized beaks and feet; and the smaller land birds show equally interesting adaptations for securing food. Bizarre adaptations for procuring food characterize the giraffe, with its long neck that enables it to reach up to feed on branches of trees fifteen feet from the ground, the ant-eater, with its sticky tongue, and the walrus, which digs bivalves with its tusks.

Scavengers

Some forms of life are not only omnivorous in their diet, but are actually scavengers, living on dead organic materials. The bacteria,¹ smallest of all plants, feed upon or destroy millions of tons of organic wastes which otherwise would make life on earth impossible. Think of a world without decay. Land and water would soon become

¹ See pages 165-166.

covered with the dead bodies of plants and animals. The bacteria of decay are very numerous in rich, damp soils containing large amounts of organic material. They decompose organic materials, changing them to compounds that can be absorbed by plants to be used in building protoplasm. Without decay life would be impossible, for green plants would otherwise be unable to get the raw food materials to make food and living matter.

In general all plants, both colorless and green, may be said to play a part in ridding the earth of organic wastes. The fungi, or colorless plants, get their nourishment from the dead bodies of plants and animals, while the green plants take organic wastes from the soil to be used in the manufacture of foods.

Many animals also take part in scavenging. Some of the food of the protozoa is made up of decaying unicellular material and the bacteria which cause its decay. Certain forms, especially insects, feed upon and lay their eggs in decaying flesh, while myriads of insects and their larvae help to break down decaying wood in a forest. These are only a few instances of this important function.

Food-getting in Plants

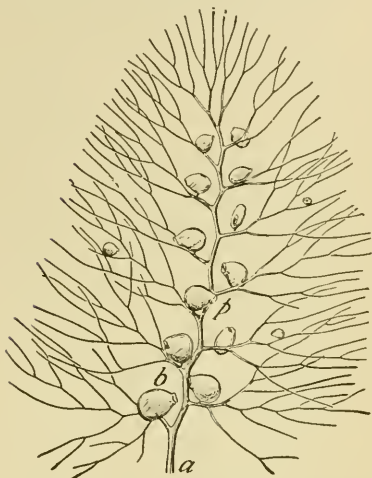
Although green plants make foods and use *raw food materials*¹ from their environment to do this, there are some that destroy foods. Fungi, such as bacteria, molds, smuts, and rusts, ruin billions of dollars' worth of food plants and plant products each year. This is seen in damage to crops, fruits, stored foods, and animals used as food by man.

Carnivorous Plants

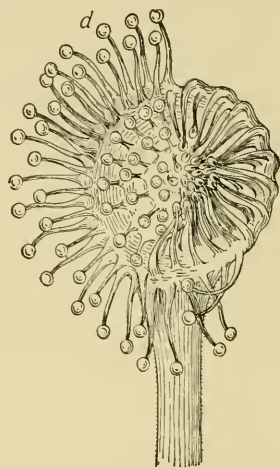
A curious exception to ordinary green plant nutrition exists in carnivorous plants, which also illustrates a different interrelationship between plants and animals. Carnivorous plants add to their nitrogen requirement in several ways. The fresh-water aquatic plants known as bladderworts (*Utricularia*) catch water fleas and other small crustaceans in living bladderlike traps. Just what lure urges the crustaceans to destruction is hard to say, but the fact that they are caught in numbers is verified by their decomposed remains found in the bladders. Other animal-eating forms are the various pitcher plants (*Sarracenia* sp.), some of which are found in our northern swamps. Insects are apparently lured to the urn-shaped leaves

¹ See pages 253-262.

by a trail of sweet nectar secreted just outside the mouth of the pitcher. Once inside, a slippery surface and incurving hairs prevent egress, and the insect is soon digested by the enzymes in the fluid contained inside the pitcher. Still another leaf modification with a similar function is seen in the sundew (*Drosera* sp.). Here the leaves are covered on one surface by sticky glandular hairs, which close



The leaf of a bladderwort (*Utricularia vulgaris*). Many of its numerous divisions bear bladders (*b*), especially near the place of attachment to the main leaf axis (*a*). Note the apertures of the bladders (*p*) into which small aquatic animals may crawl or swim.



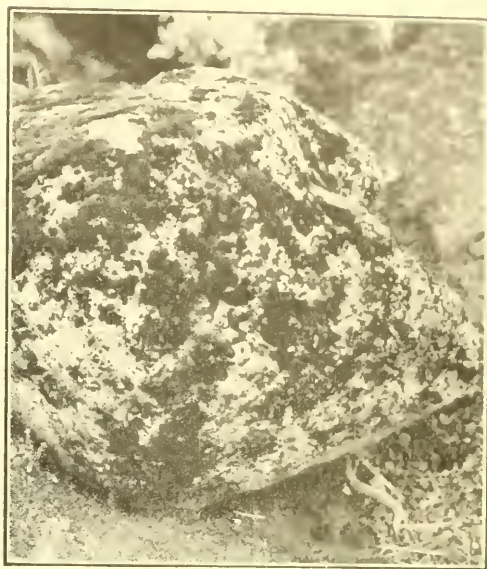
The modified leaf of a sundew (*Drosera rotundifolia*) showing the conspicuous glandular hairs (*g*) covering the upper surface, the hairs at the right having caught an insect. Note that the hairs are tipped by a drop of secreted liquid (*d*), which attracts insects to the leaf and also entangles them. — After KERNER.

over the insect, hold it fast, and ultimately digest it and absorb its juices. In the Venus's-flytrap (*Dionaea* sp.), another carnivorous plant found in some parts of this country, the leaves have two sensitive lobes provided with marginal hairs. If an insect lights on a leaf, the two lobes close over it and the insect is trapped. After its prey is digested, the lobes of the leaf open up and the plant is ready for action again.

Symbiosis

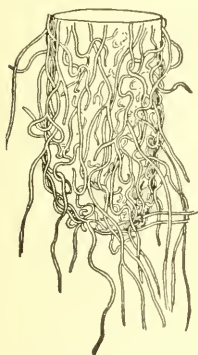
The process of living together for mutual advantage is called *symbiosis*. Plants may join forces as may animals, or in some instances, plants with animals. *Lichens*, for example, illustrate this

mutual partnership in an interesting way. A lichen is composed of two kinds of plants, a green alga and a fungus, one of which at least may live alone. The two plants form a partnership for life, the alga making the food and nourishing the fungus, while the latter gives the alga raw food materials, protects it, and keeps it from dying when the humidity of the air is low. Other examples are bacteria and the mycelial filaments of fungi (*mycorrhiza*) which live symbiotically on the roots of certain plants, taking food from the plants, but giving them nitrogen in a usable form in return.



Wright Porter

An encrusting lichen. Why does this plant succeed in such an unfavorable environment?



A root tip of the European beech (*Fagus sylvatica*), showing ectotrophic mycorrhiza, the fungal hyphae forming a dense layer which ensheathes the root.
— After FRANK.

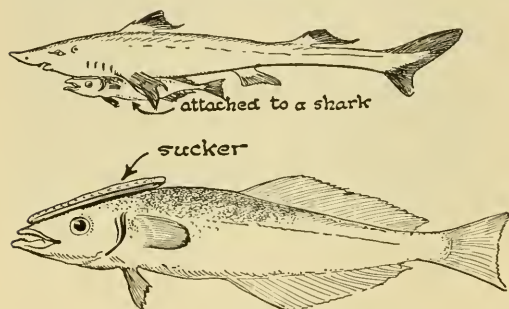
A common example of symbiosis between plants and animals is the green Hydra (*Chlorohydra viridissima*), which holds in its body wall a unicellular alga known as *Zoochlorella*. These plants contain chlorophyll, using the sun to make food. In this partnership, the algae get carbon dioxide and nitrogenous wastes from the animal, to which, in turn, they give food and the oxygen set free in the process of starch-making. There are numerous examples of this kind of symbiosis in the animal world, as is seen in many of the protozoa, sponges, coelenterates, flatworms, molluscs, and sea urchins.

The symbiotic relationship of animals to each other is shown by the tiny protozoans living in the digestive tracts of termites or white ants. These little animals act as digestive cells for the termites, making it possible for them to use wood fibers on which they live. In return the

protozoans receive food and are protected by their hosts. A somewhat similar situation prevails in the large intestine of man, where certain types of useful bacteria are found. These forms help keep down putrefying bacteria, receiving in return a home, food, and a favorable temperature in which to live. Certain species of ants protect and feed aphids, in turn feeding upon the sweet fluid secreted by the aphid.

Commensalism

Some associations are not obviously to the advantage of either organism, the two feeding together as messmates. Animals like



The shark sucker (*Remora brachyptera*, Lowe) showing sucking disk and its method of attachment to the shark. The *Remora* gets free transportation and makes sudden forays after food as well as sharing the "left-overs" of the shark's food. But it seems doubtful if the shark gains anything from the association.

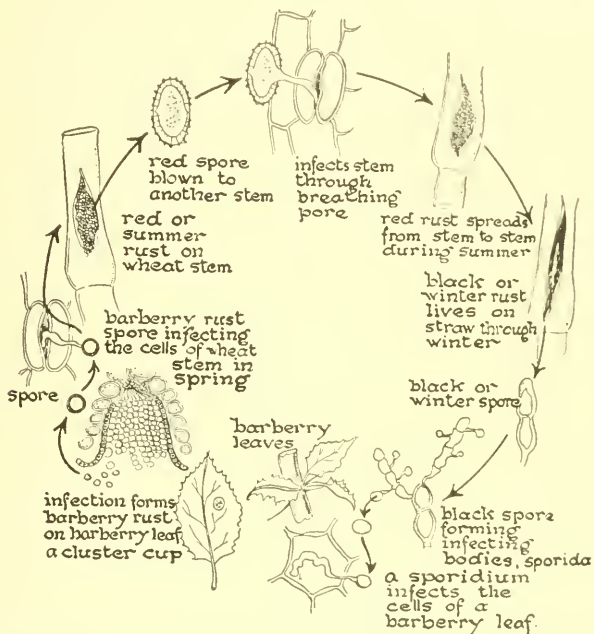
the small crabs that live in the water canals of certain sponges, or the tiny fishes that live in the lower part of the body of a "trepang," a sea cucumber, are examples. The young of some species of rudderfish (*Stromateidae*) accompany large jellyfish, seeking shelter under their stinging tentacles when chased by larger fish, while another fish (*Nomeus*) lives in constant association with the beautiful coelenterate known as the Portuguese man-of-war.

Parasitism

Not all life is give and take. Some plants and animals live at the expense of others, giving nothing and taking all. These are known as *parasites*, the organism which entertains them being called the *host*. From the lowest to the highest forms in the plant and animal kingdom there are few which are not attacked by parasites at some stage of their existence.

Parasitism implies plenty of food, shelter, and a relatively protected life for the parasite, but it also usually spells degradation in structure and loss of activity. It may mean only inconvenience, but more likely a shorter and disturbed life for the host, especially if the parasite

causes disease. In some instances, the complicated life history is so bound up with more than one host that if one of the hosts is absent, a link in the chain of life is broken, the life cycle cannot be completed, and the parasite dies. The black-stem grain rust, which requires



The life history of black stem grain rust. Explain how this rust may be controlled.

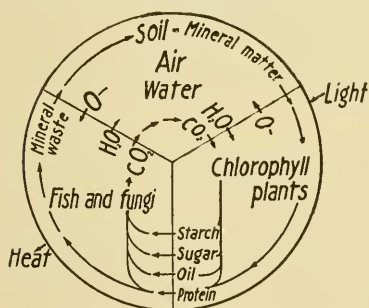
both the barberry plant and the wheat to complete its life history; the pine tree blister, which lives on the currant or gooseberry at one stage of its life history, and on the pine at another; and the parasite causing malaria, which requires both the anopheline mosquito and the blood of man to complete its cycle, are examples.

The Chemical Relationship of Plants and Animals

The study of plant and animal ecology may be said to be analogous to the study of human economics. Social conditions among men, animals, and plants are all determined by the environmental factors present, but chiefly by the availability and abundance of food. The world's food supply in the long run depends upon the chemical elements making up the environment and energy derived from the sun.

Plants and animals are made out of the same chemical elements. Burn some beans or a piece of beefsteak, a piece of wood or a bit of living bone, an entire green plant or a dead mouse, and the chemist would tell us that the same chemical elements are present in animals and plants; that certain of these elements passed off in the smoke, others into the air as colorless gases, leaving still others as a whitish ash. All living things are composed mainly of carbon, oxygen, hydrogen, nitrogen, with about twelve other chemical elements found in very minute quantities. These elements are all present in the immediate environment of plants and animals, air, water, and soil.

How they get from the basic environment into living things can be briefly stated. Carbon, which is contained in all organic foods and in this condition is taken into the animal body, can only be absorbed in the form of carbon dioxide by food-making green plants. This gas, which is present in the atmosphere to the average amount of about 0.03 per cent, gets there as a result of oxidative processes taking place in plants and animals, as well as by the combustion of organic substances. Factories and volcanoes alike form their quota of carbon dioxide to diffuse out into the atmosphere. The cycle of the passage of carbon from plants to animals and from animals back to plants is shown in the accompanying figure.



The carbon and oxygen cycles in a balanced aquarium. Trace the passage of an atom of carbon from a green plant back to the plant.

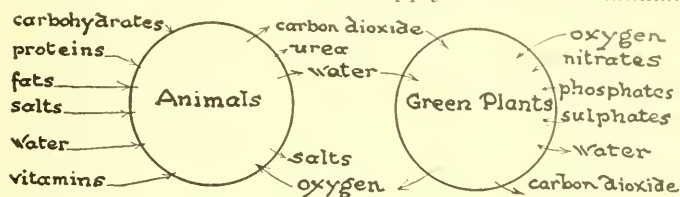
plants add this gas to the air during the process of starch-making.

Nitrogen is one of the most important elements found in living things. Making up 79 per cent of the air, it is not usable in the form of a gas except by the nitrogen-fixing bacteria.

Hydrogen, another component part of living things, cannot be used in its pure state by either plants or animals. In water (H_2O), it becomes an important part of the food of animals, and as water vapor it is used in starch-making by green plants.

Oxygen is freely available to both plants and animals. As a gas, making up over 20 per cent of the air, capable of being dissolved in water for aquatic plants and animals, it is used by all living things in respiration. Green

The other mineral components of living matter, of which sulphur, phosphorus, calcium, potassium, and iron are among the most important, are all found either in water, soil, or both. How the plant makes use of them and turns them over for the use of animals is an interesting story to be told later. But enough has been said to show that foods made by the green plants form the supply on which all animals live.



The food relationships between green plants and animals.

Life Habits of Bacteria

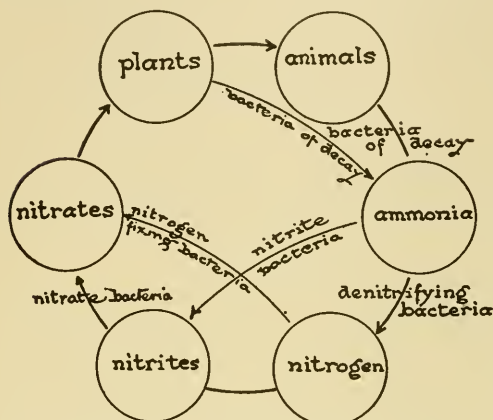
In this web we call life, bacteria play a most important part. Since bacteria contain no chlorophyll, they are unable to make carbohydrate food, and must obtain their foods from decaying organic matter. In order to absorb such food it must be made soluble so that it will pass into their bodies. This they do by digesting food substances by means of enzymes¹ which they secrete. Bacteria that grow or thrive in the presence of oxygen are called *aerobic*, while those which live without free oxygen are called *anaerobic*. The latter need oxygen, like other living things, obtaining it by breaking down the foods on which they live, and utilizing oxygen freed in this process.

Relation of Bacteria to Free Nitrogen

It has been known since the time of the Romans that the growth of clover, peas, beans, and other legumes causes soil to become more favorable for the growth of other plants, but the reason for this was not discovered until modern times. On the roots of the plants mentioned are found little nodules, or tubercles, in each of which are millions of nitrogen-fixing bacteria (*Rhizobium leguminosarum*), that take nitrogen gas from the air between the soil particles and build it into nitrites which are then converted by other bacteria (*Nitrobacter*) into nitrates. In this form it can be used by plants. Nitrogen-fixing bacteria live in a symbiotic relationship with the plants on which they form tubercles, their hosts providing them with organic food.

¹ See pages 127-128.

Bacteria also act upon ammonia formed from plant and animal wastes, one kind (*Nitrosomonas*) producing nitrites, or nitrate salts, and others (*Nitrobacter*) converting the nitrites into the more stable nitrates. Thus all of the compounds of nitrogen are used over and over, first by plants, then as food by animals, eventually returning to the soil, or in part being released as free nitrogen. This process is



The nitrogen cycle. What additions could be made to this diagram?

called the nitrogen cycle. Although free nitrogen is fixed for use by means of electrical discharges during thunderstorms, by man-made machines, by ultraviolet light (which is estimated to return 100,000,000 tons a year to the earth's surface), and from other sources, yet these means give an almost negligible amount of usable nitrogen to the soil, compared with what

is used in crop production, especially since so much nitrogen is lost from the soil in various ways. The nitrogen-fixing bacteria supply the deficiency, thus forming one of the most important inter-relationships between plants and animals because of their direct relationship to the production of the food of the world.

Rotation of Crops

Plants that are hosts for the nitrogen-fixing bacteria are raised early in the season, then plowed under and a second crop of a different kind is planted. The latter grows quickly and luxuriantly because of the nitrates left in the soil by the bacteria which lived with the first crop. For this reason, clover is often grown on land used later for corn, or cowpeas will be followed by a crop of potatoes. On well-managed farms, different crops are planted in succession in a given field in different years so that one crop may replace some of the elements taken from the soil by the previous crop. This is known as rotation of crops.¹

¹ Crop rotation is not only a process to conserve the fertility of the soil, but also a sanitary measure to prevent infection of the soil.

The Relations between Insects and Flowers

One of the most interesting symbiotic relationships is that which exists between insects and flowers. Flowering plants produce seeds

and fruits, and from these come new generations of plants, but if it were not for the visits of insects, many plants would not produce seeds.

Insects visit flowers in order to obtain nectar, a sugary substance formed by the nectar glands, and pollen. The glands which produce the nectar are usually so placed that an insect

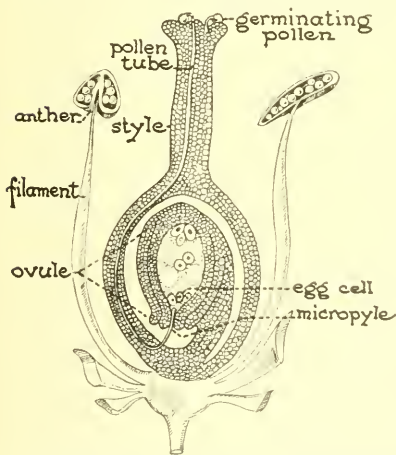


Wright Pierce

Tiger Swallow-tail (*Papilio turnus*) on rose.

has to push its way past the stamens and pistil of the flower in order

to reach the desired food. In doing this, pollen grains may adhere to the hairy covering of the insect and be transferred to the sticky surface of the upper end of the pistil (*stigma*). Inside the pollen grains are the male reproductive cells (*sperms*), while in the ovary of the pistil are held the female reproductive cells (*eggs*). In order to have development of a new plant, it is essential for a sperm cell to unite with an egg cell. Pollen grains on the stigma are stimulated to send out hairlike tubes, which penetrate the stalk (*style*) of the pistil and eventually reach the *ovary*. The pollen tube carries one or more



A longitudinal section of the reproductive organs of a flower showing the penetration of a pollen tube through the opening in the pistil called the *micropyle*, and the growth of the pollen tube to the *ovule*.

sperm cells, which are thus enabled to unite, each with a single egg cell, in the ovule of the pistil. The union of the *sperm nucleus* with its *egg nucleus* is called *fertilization*. As a result of this process the fertilized egg develops into an embryo or young plant which is held in the seed. When favorable conditions arise, this embryo may develop into a plant.

Bees are the chief pollinizing agents, although butterflies, moths, flies, and a few other insects perform this service as well. Hummingbirds often pollinate tubular flowers, while other small birds, snails, and even bats are agents in the pollination of certain forms. Man and animals may accidentally pollinate flowers in brushing past them through the fields. The value of cross-pollination is obvious and is an example of the close weaving of life in which man, animals, and plants are all inescapably entangled.

SUGGESTED READINGS

Borradale, L. A., *The Animal and Its Environment*, Oxford University Press, London, 1923. Chs. IV, V, XIV.

Excellent for reference.

Elton, C., *Animal Ecology*, The Macmillan Co., 1935. Chs. V, VI, VIII.

Particularly valuable on the animal community and the relationship of animals to a food supply.

Needham, J. C., and Lloyd, J. T., *Life of Inland Waters*, 2nd ed., Charles C. Thomas, 1930. Ch. V.

Interrelationships among fresh-water organisms.

Pearse, A. S., *Animal Ecology*, McGraw-Hill Book Co., 1926. Chs. VIII, X. A wealth of material on interrelationships.

Rau, Phil., *Jungle Bees and Wasps of Barro Colorado Island*, privately printed, Kirkwood, St. Louis, 1933.

An ecological study of a tropical environment.

Wallace, A. R., *The Geographical Distribution of Animals*, 1876. Books I and II. Ch. IV, especially.

This book forms the basis for most of the modern work in distribution. All of Part III, Books I and II, is extremely interesting.

Weaver, J. E., and Clements, F. E., *Plant Ecology*, McGraw-Hill Book Co., 1935. Ch. XVI.

An interesting chapter on relations between plants and animals, with especial emphasis on insect pollination.

Wells, H. G., Huxley, J. S., and Wells, C. P., *The Science of Life*, Doubleday, Doran & Co., 1931. Book 6, Chs. IV and V.

A fascinating book for general reading.

IV

ROLL CALL

PREVIEW. Early contributions to classification · Binomial nomenclature · Law of priority · What is a species? · A classification of plants and animals · Classification of the plant kingdom · Classification of the animal kingdom · Glossary of terms occurring in the Roll Call.

PREVIEW

It is hoped that this section will be freely used by the student. It is not expected that the classification of plants and animals will be learned by rote, but rather used for reference from time to time as new forms are seen. By this means the diagnostic characteristics of different phyla and classes will gradually be learned as needed, and the relationship of one group to another become more apparent.

In order to enjoy hikes or longer trips, the student should be able to recognize the larger groups of the plant and animal kingdoms. Fortunately there are museums, botanical gardens, and zoological parks to which one may refer, all the more intelligently of course if he has himself first discovered living animals and plants.

Identifying plants and animals correctly becomes more of a pleasure than a task, if the principles of scientific, as well as common, nomenclature are understood. Both scientific and common names will be encountered. The former are written in the dead, unchanging Latin language, and are of more universal usefulness, since the latter are frequently misleading and confusing, as more than one common name may be applied in different countries, or in different parts of the same country, to a single plant or animal. For example, the common "chain pickerel" is listed under the scientific name of *Esox*, indicating the larger or *generic* group to which the fish belongs, and *niger*, which is its *specific* name, but it has at least twenty-two common names in different parts of this country. Here are a few of them: black pickerel, pike, common eastern pickerel, duck-bill pickerel, green pike, little pickerel, and lake pickerel. The terms pike, pickerel, and lake pickerel are also quite commonly used in some parts of the country to designate another fish, the great northern pike, *Esox lucius*. In still other localities "pike" refers to an entirely different group, the pike-perches, belonging to the genus *Stizostedion*. This example will

serve to indicate the necessity for the use of Latin scientific names in classification. There may be other members of the genus *Esox*, but there is only one *niger*, although *varieties* of the same are possible in different environments. The terms of *genus* and *species* were introduced to the scientific world in the middle of the 18th century by Carl von Linné (1707–1777), of Sweden.

The study of classification is called *Taxonomy* and is subdivided into zoological taxonomy, or *Systematic Zoology*, and botanical taxonomy, or *Systematic Botany*.

Early Contributions to Classification

In order to secure an idea of the development of taxonomy it is necessary to go back several hundred years to some of the earlier biologists and glance at a few of the contributions of these students. Obviously such an excursion can hope to touch upon only a few of the more important workers. Logically, one should go all the way back to Aristotle's time, but lack of space forbids such an interesting excursion. Consequently we must confine ourselves to the immediate forerunners of Linné, or Linnaeus as he came to be called, who introduced the concept of *binomial nomenclature* and with it a more adequate idea of *genus* and *species*.

In 1576, Matthias de l'Obel published an important work on plants. This was an attempt to arrange plants according to their structure. He took the shape of the leaf as the basis for this classification, and it led him to put such things as *ferns* in the same group with *trees* because the fronds of the fern bore a superficial resemblance to the needles of the hemlock. Another botanist was the Swiss, Kasper Bauhin (1560–1624), who described in order 6000 species of plants, beginning with the ones he considered most primitive. He approached the concept of genus and species, because he grouped together plants which resembled one another externally.

John Ray (1627–1705) deserves recognition along with Linnaeus as the founder of the science of systematic biology. This enthusiast published a catalogue of British plants in 1670 and later works (1703) in which he introduced and explained the groups of *Monocotyledons* and *Dicotyledons*. He also made less extensive contributions to the classification of animals. Some of these he published with his good friend Willughby (1635–1672). Ray gave evidence in his work that he realized the fundamental differences between genus and species; furthermore, he had the keenness to group together both related plants

and animals. Ray also advanced the idea that fossils are extinct species.

Linnaeus was born in 1707, the son of a Swedish clergyman. He would have been destined to become a cobbler had it not been for the influence of a physician who recognized the lad's abilities. To make a long story short, he finally secured his medical degree, aided in no small amount by the contributions of his fiancée, and eventually became a professor of natural history at Upsala. It seems that Linnaeus had a passion for natural history and for classifying everything which came to hand. He initiated several changes in the study of systematic biology, many of which are still in use today.

Binomial Nomenclature

The most important contributions of Linnaeus center about (1) brief, clear, and concise diagnoses; (2) sharper divisions between groups; and (3) a definite, clear-cut system of scientific terminology, known as *binomial nomenclature*. These innovations appeared in the 1753 edition of *Species Plantarum* and the 1758, or tenth, edition of his great work, the *Systema Naturae*. The tenth edition of this latter work is taken as the starting point of zoological nomenclature. Linnaeus divided the plant and animal kingdoms into *Classes*, *Orders*, *Genera*, and *Species*. This was a great step over the use of popular common descriptive terms, as you can now appreciate if you refer back to the example of the pickerel. However, a big mistake made by Linnaeus was his concept of fixity of species.

In 1898 the International Congress of Zoology appointed an international commission which drew up a set of rules applying to the divisions of the animal kingdom. Thus classification today is really an expansion of the Linnæan system which now includes in the case of the animal kingdom, for example, the following:

ANIMAL KINGDOM — is made up of
 PHYLA — each of which is composed of
 CLASSES — in turn made up of
 ORDERS — then
 FAMILIES — and finally
 GENERA — and
 SPECIES.

In the plant kingdom a comparable arrangement is utilized, beginning with DIVISIONS (= phyla).

Law of Priority

In describing species it sometimes happened that more than one person described the same form, giving it different names. In such cases the name assigned by the one who first described it is used, the second being considered a synonym. This is the reason for writing the describer's name and date of publication after the specific name. Ordinarily the date and frequently the describer's name is omitted. Thus the true daisy is properly *Bellis perennis*, Linn. 1758, or the English sparrow, *Passer domesticus*, Linn.

What Is a Species?

We have taken a glimpse at the contributions of some of the contemporaries and near contemporaries of Linnaeus and have gained a slight concept of the problems these early workers faced in defining and describing a species. Biological scientists of today are still working on this problem. The principle involved is readily understood when we look at a sheep, a cat, and a dog. One can easily separate them from each other, various cats being put in one group and diverse dogs in another. All domestic cats, whether they be the alley variety or pet Persians, and all dogs, whether they be a "dog in the manger" or "man's best friend," fall into well-marked and easily separable groups, known as *species*. To continue further, one finds in looking over representative mammals that many other species such as the jaguars, ocelots, jaguarundis, and cougars, all have certain characteristics in common with our domestic cats. These characteristics are size, build, shape of head, nature of claws, teeth, and fur. The zoological systematist, therefore, places them in one larger group or *genus* which is called *Felis*, a relationship expressed below.

Kingdom -	<u>Animal</u> , Plant
Phylum -	<u>Chordata</u> , Arthropoda, Mollusca, etc.
Class -	<u>Mammalia</u> , Pisces, Reptilia, Aves, etc.
Order -	<u>Carnivora</u> , Rodentia, Chiroptera, etc.
Family -	<u>Felidae</u> , Canidae, Ursidae, etc.
Genus -	<u>Felis</u> , <u>Lumbricus</u> , etc.
Species -	<u>domestica</u> , leo, tigris, etc.
Individual -	<u>Tom</u> , Dick, Harry, etc.

However, species have other characteristics besides external or morphological similarities. They breed true, that is, cats produce cats, and dogs produce dogs. Usually different species cannot be crossed. There are exceptions, for sometimes one species crossed with another may yield a sterile hybrid. Thus a horse crossed with an ass produces a *mule*. But on the whole the preceding statement holds true.

Two criteria have been used in classifying organisms, first, structural differences, or appearance, which really means *comparative morphology*, checked *physiologically* and *genetically* by the cross-breeding of species, and second, the approach through a study of the early development and the life cycle, *embryology*, and the distribution of the organism, *ecology*. The latter leads to a consideration of varieties, subspecies, and races, which through intergradations often complicate the problem of determining species.

Such a study may be made either more complicated or facilitated according to whether a so-called *natural classification* or *artificial classification* is utilized. Thus bats and birds might be artificially classified together, simply because they both fly, just as whales and fishes are placed together by the ignorant, because both inhabit the water. A careful study of the anatomy and development of these animals would indicate that if one is trying to show relationships, which is what a classification should do, bats and whales would both have to be put in the mammalian group.

Determination of the type of symmetry present is useful in classification. Some organisms possess a *universal symmetry*, as the protozoan *Volvox*. In such cases the organism is divided into equal halves by any plane that passes through the center. Starfish and hydra, on the other hand, are well-known examples of *radial symmetry*. In such forms there is a single axis, as may be seen in a cylinder, and a number of planes through such an axis would divide the organism into symmetrical halves. Most of the more highly developed forms possess *bilateral symmetry*, which is characterized by similar halves on either side of a main axis. Other secondary planes occur in bilaterally symmetrical animals, resulting in anterior-posterior, and in dorso-ventral differentiation. Sometimes segmentation, or metamerism, is apparent, as in the case of the earthworm and many of the Arthropods.

If one attempts a classification that is based primarily upon structure, it is necessary to differentiate between *homology* and *analogy*.

The former refers to similarity of *structure* and the latter to similarity of *function*. Thus the forelimbs of a bat, bird, cat, and turtle are all homologous, while the wings of a bat or a bird are analogous to the wings of a butterfly, but they are not homologous since they differ in structure.

A Classification of Plants and Animals

As stated earlier, the appended scheme of classification is simply a tool to be used by the student. Remember that a scheme of classification is not only the "who's who" of the plant and animal world but it shows *relationships* as well, indicating what we know at present in this field. Classification involves a knowledge of the occurrence, distribution, development, and structure of the form studied, and so is much more than simply applying a scientific name to an animal or plant. The use of scientific names cannot readily be avoided, as will be realized from a study of these pages. If one really desires to excel in biological work, he must set out cheerfully and with determination to acquire an understanding of the use of these tools as an indispensable aid to a comprehension of the interrelationship of organisms to one another.

In the first place it is hoped that diagrams which accompany this classification are detailed enough to give the student some concept of the more common or important kinds of representative organisms occurring in each group. It is unfortunately impossible in these drawings to represent the different animals according to scale. The student hardly needs, however, to be reminded that whales and protozoans should be interpreted as decidedly different in size. In most cases, the classification will be carried only as far as the class, although in a few groups, as with the Arthropoda and Tetrapoda, it is necessary to go to the orders. In some instances attempts have been made to simplify the classification in order to avoid unnecessary scientific terminology. It should be added that the classification here presented is only *one* of *many* that may be encountered in various books, differing in details but agreeing in essential particulars.

It is impossible to designate readily all of the characteristics which are utilized in the separation of the larger plant and animal groups. However, it is of importance to know (1) whether we are dealing with a one- or many-celled form (uni- or multi-cellular); (2) the number of germ layers present in the organism, *diploblastic* — two (ectoderm and endoderm); *triploblastic* — three (ectoderm, endoderm, and

mesoderm); (3) the nature of the body — usually divisible into tubes within tubes or sacs; (4) the symmetry — radial or bilateral; (5) the nature of the appendages — if present, whether jointed or non-jointed, paired or unpaired; (6) whether the organism is segmented or non-segmented; (7) which organ systems or organs are present, in what form they occur and how they function; (8) type of skeleton, absent, exo- or endoskeleton; (9) the presence or absence of a notochord; (10) the presence or absence of special organs; (11) the type of tissues present, as bark, phloem, muscular, or circulatory.

Inasmuch as some of these and other terms appearing in the scheme of classification are new, a short glossary is included. This is designed to elucidate terms used in the appended classification. Other words are defined as they are first used in the text and may be found by reference to the index.

CLASSIFICATION OF THE PLANT KINGDOM

(mainly after Sinnott)

All members of the plant kingdom are characteristically sessile; typically possess chlorophyll; usually take food in inorganic form; cell walls of cellulose or hydrocarbon.

DIVISION I — THALLOPHYTA — Thallus Plants (algae,¹ fungi, bacteria).

CHARACTERISTICS: Small, often minute, little differentiated plants sometimes possessing chlorophyll; sex organs, when present, typically one celled; spore-bearing organs are single celled; 80,000 species.

Subdivision A — **Algae** — Composed mostly of blue-green, green, brown, or red algae.

CHARACTERISTICS: Chlorophyll frequently associated with other pigments; manufactures own food.

CLASS I — CYANOPHYCEAE — Blue-green algae (*Gloeocapsa*, *Nostoc*, *Oscillatoria*).

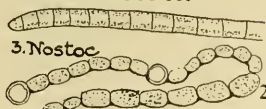
CHARACTERISTICS: Simplest and lowliest of green plants; body consists of a single cell with nucleus; sap cavity and chloroplasts absent; often tending to adhere in colonies; usually in threadlike rows (*filaments*); cytoplasm homogeneous, pigment evenly dispersed, or a colored outer and a colorless inner zone may be distinguishable; blue-green color probably due to chlorophyll mixed with blue pigment (*phycocyanin*).

CLASS II — CHLOROPHYCEAE — Green algae (*Carteria*, *Ulva*, *Ulothrix*, *Oedogonium*, *Vaucheria*, *Spirogyra*).

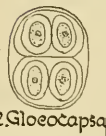
¹ Genera in boldface type indicates that the form is illustrated in this unit.

Class I
Cyanophyceae
blue-green algae

1. Oscillatoria

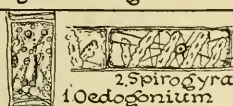


3. Nostoc



2. Gloeocapsa

Class II
Chlorophyceae
green algae



1. Oedogonium

2. Spirogyra



3. Ulva

4. Ulothrix



4. Ulothrix

SUBDIVISION A
ALGAE

Class IV
Phaeophyceae
brown algae

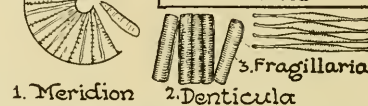


1. Laminaria

2. Fucus

3. Ullopteryx

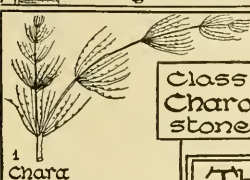
Class V
Diatomaceae
diatoms



1. Meridion

2. Denticula

3. Fragillaria



1. Chara

Class III
Charophyceae
stonewarts



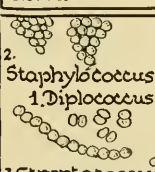
1. Polysiphonia

3. Corallopsis

2. Phyllophora

Class VI
Rhodophyceae
red algae

THALLOPHYTA
algae, fungi, bacteria



2. Staphylococcus

1. Diplococcus

3. Streptococcus

4. Bacillus

5. Spirillum

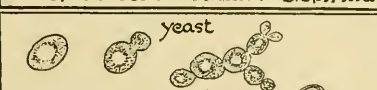
1. Saprolegnia

Class I.
Schizomycetes
bacteria

Class IV
Phycomycetes
alga-like fungi



2. Mucor

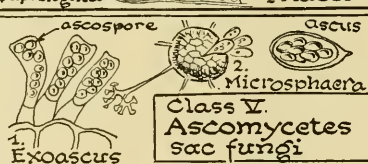


yeast

Class II
Saccharomycetes
yeasts



spore



1. Exoascus

Class V.
Ascomycetes
sac fungi



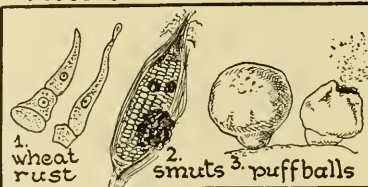
1. Hemitrichia

2. Comatrichia

3. Trichamphora

Class III.
Myxomycetes
slime fungi

SUBDIVISION B
FUNGI



1. wheat rust

2. smuts

3. puffballs

Class VI.
Basidiomycetes
smuts and rusts

CHARACTERISTICS: Chlorophyll associated with carotin and xanthophyll; marine or fresh water organisms, or inhabitants of moist land; nucleus and one or more chloroplasts present; starch synthesized in *pyrenoids*; plant composed of single cells, colony, filament, or plate of cells; most species produce motile reproductive cells (*zoospores*); both equal (*isog-*) and different sized (*hetero-*) gametes present.

CLASS III — CHAROPHYCEAE — Stonewarts (*Chara* and *Nitella*).

CHARACTERISTICS: Vegetative body consisting of long, jointed stems with whorls of short branches arising at joints (*nodes*); asexual spores absent; more complicated *antheridia* and *oögonia* than found in Thallophytes borne along branches.

CLASS IV — PHAEOPHYCEAE — Brown algae, kelps, rockweeds, sargassum (*Laminaria*, *Fucus*, *Uloperyx*).

CHARACTERISTICS: Multicellular; exclusively marine; brown color (due to one or more brown pigments associated with chlorophyll); normally found in intertidal zone.

CLASS V — DIATOMACEAE — Diatoms (*Meridion*, *Diatoma*, *Denticula Fragillaria*).

CHARACTERISTICS: Large group of unicellular algae; related in color to brown algae; common as plankton organisms in both fresh and salt water; siliceous walls.

CLASS VI — RHODOPHYCEAE — Red algae (*Nemalion*, *Polysiphonia*, *Phyllophora*, *Corallopsis*).

CHARACTERISTICS: Mostly marine; characteristically reddish in color; branched, vegetative body filamentous and delicate; grow entirely submerged; cell wall often thick, gelatinous; color due to pigment, *phycoerythrin*; no motile cells; sexual reproduction highly specialized.

Subdivision B — Fungi — Fungi, bacteria, and molds.

CHARACTERISTICS: Chlorophyll lacking; exist as parasites or saprophytes.

CLASS I — SCHIZOMYCETES — Bacteria (*Diplococcus*, *Staphylococcus*, *Streptococcus*, *Bacillus*, *Bacterium*, *Spirillum*).

CHARACTERISTICS: Unicellular plants, usually without pigment, dividing in one, two, or three planes; apparently structureless, but probably containing a diffuse nucleus.

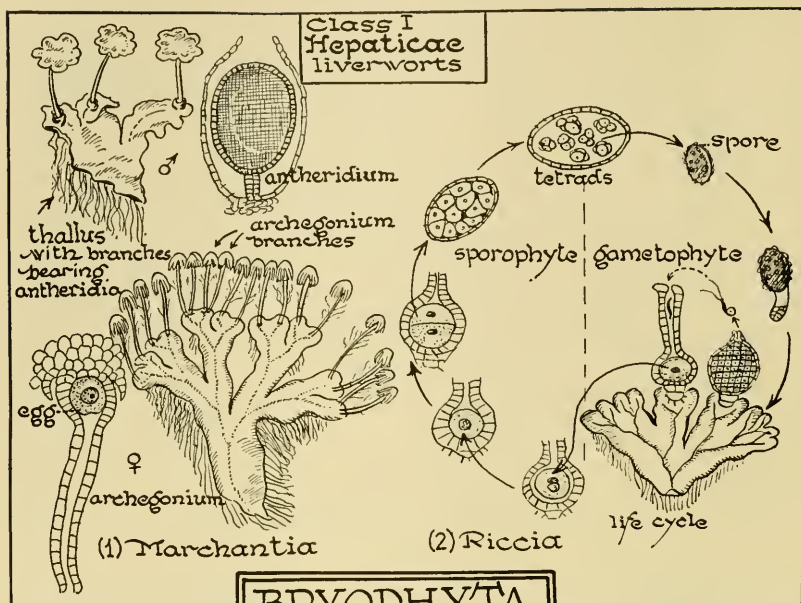
CLASS II — SACCHAROMYCETES — Yeasts (*Saccharomyces*).

CHARACTERISTICS: Sometimes regarded as reduced Ascomycetes; single cells with definite nucleus; cytoplasm and sap cavity; buds asexually; under unfavorable conditions forms four spores, in a modified ascus.

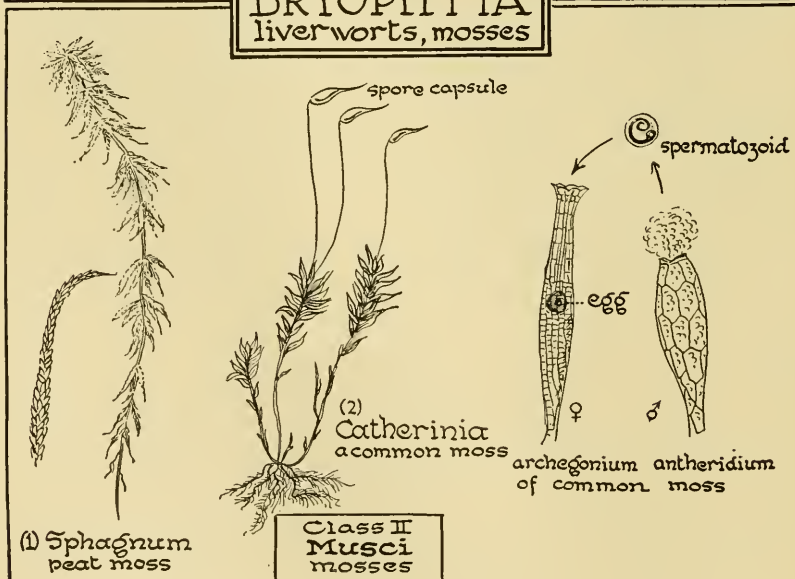
CLASS III — MYXOMYCETES — Slime fungi, slime molds (*Hemitrichia*, *Comatricha*, *Trichamphora*).

CHARACTERISTICS: Border-line plants; spores borne by fruiting bodies, germinating into small, naked mass of protoplasm without a wall; individual cells fuse, forming a *plasmodium*.

CLASS IV — PHYCOMYCETES — Algalike fungi, molds, and blights (*Saprolegnia*, *Mucor*).



BRYOPHYTA
liverworts, mosses



CHARACTERISTICS: Resemble algae; plant body consists of filaments (*hyphae*) which are not divided into cells by cross walls; multinucleate.

CLASS V — ASCOMYCETES — Sac fungi (*Morchella*, *Exoascus*, *Microsphaera*).

CHARACTERISTICS: Includes over 20,000 species, mostly saprophytes or parasites; body consists of branching *mycelium* throughout substratum and a definite fruiting body at surface; produce spore sacs (*asci*) containing eight spores (*ascospores*); group of *asci* embedded in sterile hyphae may or may not be surrounded by protective envelope.

CLASS VI — BASIDIOMYCETES — *Basidia* fungi, smuts and rusts, wheat rust (*Puccinia*), puff balls.

CHARACTERISTICS: Large and varied group; specialized reproductive structure (*basidium*) is swollen terminal cell of hypha, in mushrooms the *basidium* usually bears four *basidiospores*, each carried on a delicate stalk (*sterigma*); sexual reproduction rare; *lichen*—composite plants in which algal cells are entangled in mycelium. Usually regarded as a parasitism of algal member rather than an example of symbiosis.

DIVISION II — BRYOPHYTA — Liverworts and Mosses.

CHARACTERISTICS: Alternation of generations in which sexual (*gametophytic*) stage dominates; asexual (*sporophytic*) stage typically parasitic upon the gametophyte; archegonium and multicellulate antheridium present; gametophyte contains x number of chromosomes while the $2x$ number occurs in the sporophyte; careful study of archegonium reveals typical flask shape, with sterile cells (*neck* and *venter*) surrounding the egg and associated cells; antheridium more or less stalked and consisting of layer of jacket cells surrounding cuboidal sperm mother cells.

CLASS I — HEPATICAE — Liverworts (*Marchantia*, *Riccia*).

CHARACTERISTICS: Intermediate between green algae and higher plants; thallus flattened and attached to soil by *rhizoids*; growth by repeated division of single large apical cell.

CLASS II — MUSCI — Mosses (*Sphagnum*, *Polytrichum*, *Catherinia*).

CHARACTERISTICS: In every habitat except salt water; very common in alpine and arctic regions; gametophyte erect, consisting of stalk with spirally arranged leaves; attachment by rhizoids.

SUBDIVISION A primitive vascular plants



SUBDIVISION B Lycopsidea club mosses



SUBDIVISION C Sphenopsida horsetails

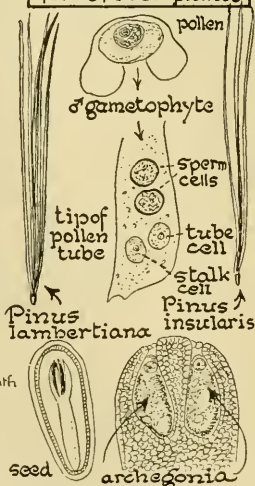


TRACHEOPHYTA vascular plants



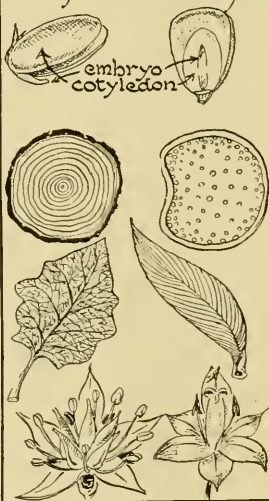
Class I Filicineae ferns

SUBDIVISION D Pteropsida ferns, seed plants



Class II Gymnospermae evergreens

dicotyledon monocotyledon



Class III Angiospermae oak, maple, elm, etc.

DIVISION III — TRACHEOPHYTA — Vascular Plants.

CHARACTERISTICS: Fibro-vascular system for transportation of raw materials up and food down; separation of specialized chlorophyll-bearing tissue; adaptation to absorption of water from soil.

Subdivision A — Primitive Vascular Plants — (*Psilotum* and *Tmesipteris*, *Rhynia*).

CHARACTERISTICS: Fossil primitive vascular plants giving rise in three lines to Lycopsidea, Sphenopsida, and Pteropsida.

Subdivision B — Lycopsidea — Club mosses, ground pines (*Lycopodium*, *Selaginella*).

CHARACTERISTICS: Stem clothed with small, numerous, spirally arranged leaves; *sporangia* borne on upper surface of *sporophyll*; latter usually grouped into terminal cones.

Subdivision C — Sphenopsida — Horsetails (*Equisetum*).

CHARACTERISTICS: Hollow, typically jointed stems, bearing small leaves at joints (nodes); stems ribbed; diaphragms often across stem at nodes; sporangia borne in groups on stalked shield-shaped structures forming terminal cones; ribs opposite fibro-vascular bundles which are associated with small air-filled canal; abundant in Paleozoic age; now only about 35 species.

Subdivision D — Pteropsida — Ferns and seed-bearing plants.

CHARACTERISTICS: Typically large leaves; sporophytic generation dominates; sporangia relatively large.

CLASS I — FILICINEAE — Ferns.

CHARACTERISTICS: Small, herbaceous plants with typical pinnately compound leaves (*fronds*); stem relatively weak and inconspicuous; roots numerous but do not form an extensive system; small sporangia borne on lower surface of leaf in groups usually protected by membrane (*indusium*); spore germinates, forming small, thin gametophyte (*prothallus*), which in turn bears antheridial and archegonial structures. About 15,000 species, some of which reach a height of 30 feet. From forms like the ferns evolved the higher vascular plants which dominate the earth's surface today.

CLASS II — GYMNOSPERMAE — Evergreens, pines, hemlocks, spruces, junipers.

CHARACTERISTICS: Seeds freely exposed to air; usually nondeciduous types; *megaspore* retained within *megasporangium* where it germinates producing female gametophyte; *integument*, a new structure, encloses a sporangium and embryo sac; reduced male gametophyte transferred directly to vicinity of female; male obtains access to female gametophyte by new structure (*pollen tube*); young sporophyte develops in contact with and at expense of parental sporophyte; gametophyte with haploid (*x*) number of chromosomes entirely parasitic upon sporophyte. Members of this group are phylogenetically ancient; only about 150 living species.

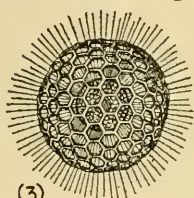
CLASS III — ANGIOSPERMAE — Deciduous trees and plants, *Dicotyledons*, oak, maple, beech; *Monocotyledons*, corn.

Class I Sarcodina



(1)
Ameba

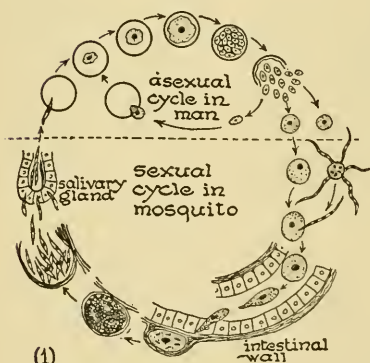
(2)
Arcella



(3)
Radiolaria

PROTOZOA

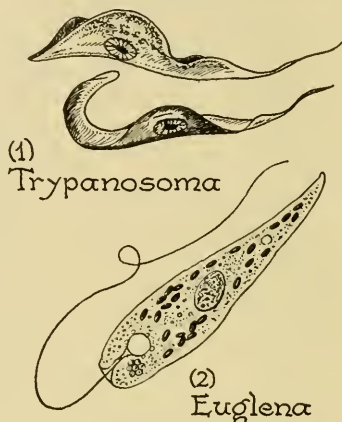
one celled animals



(1)
Plasmodium

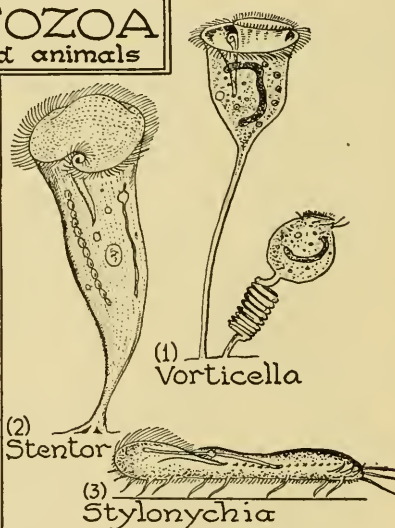
Class III Sporozoa

Class II Mastigophora



(1)
Trypanosoma

(2)
Euglena



(1)
Vorticella

(2)
Stentor

(3)
Stylonychia

Class IV Infusoria

CHARACTERISTICS: Seeds enclosed by a case (*ovary*), so that pollen grain does not reach the ovule but rests on surface of carpel; closure to form case probably arose by folding together of edges of megasporophyll (*carpel*); pollen received on special organ (*stigma*) at tip of ovary. Members of this group probably were derived from gymnosperm stock; now number 135,000 species and are subdivided into dicotyledons and monocotyledons which may be separated by the following characteristics:

	DICOTYLEDONS	MONOCOTYLEDONS
Number of cotyledons of embryo . . .	two	one
Vascular bundles . .	arrange to form vas-cylinder enclosing pith	scattered
Leaves	open venation, veinlets ending freely in margin, which is often toothed or lobed	closed venation (<i>i.e.</i> parallel) margin therefore entire
Flowers	in sets of four or five	in sets of three

CLASSIFICATION OF THE ANIMAL KINGDOM (mainly after Hegner)

All members of the animal kingdom are characteristically free-moving organisms; generally capable of assimilating organic foods; rarely possessing chlorophyll; cell membranes composed of protoplasm or proteins.

PHYLUM I — PROTOZOA — One-celled animals.

CHARACTERISTICS: Single cells or colonies of loosely aggregated unspecialized cells; rarely differentiated into germ cells; 8500 species.

CLASS I — SARCODINA — Naked protozoa (*Ameba*,¹ *Arcella*, *Radiolaria*).

CHARACTERISTICS: Locomotion by means of pseudopodia.

CLASS II — MASTIGOPHORA — Flagellate protozoa (*Euglena*, *Trypanosoma*).

CHARACTERISTICS: Locomotion by means of flagella.

CLASS III — SPOROZOA — Parasitic protozoa (*Lankesteria*, *Myxosporidia*, *Plasmodium*).

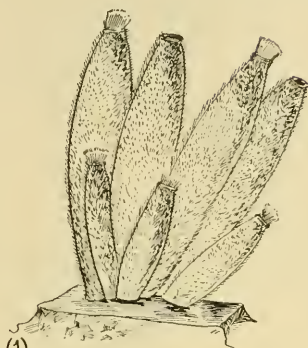
CHARACTERISTICS: No organs of locomotion in adults; endo-parasites reproducing by schizogony and spore formation.

CLASS IV — INFUSORIA — Ciliate protozoa (*Vorticella*, *Stentor*, *Stylonychia*, *Paramecium*).

CHARACTERISTICS: Locomotion by means of cilia.

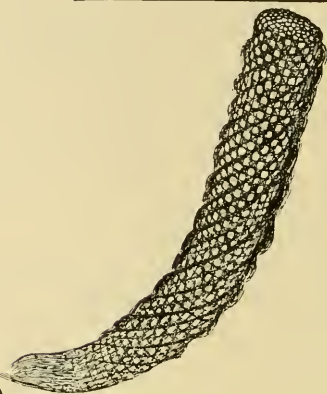
¹ See footnote at beginning of classification of Plant Kingdom.

Class I
Calcarea



(1)
Grantia

Class II
Hexactinellida

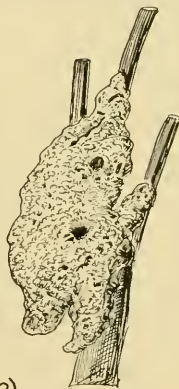


(1)
Euplectella
Venus' flower basket

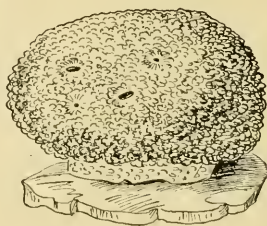
PORIFERA
sponges



(1)
Chalina
finger sponge



(2)
Spongilla
fresh-water sponge



(3)
Euspongia
bath sponge

Class III
Demospongia

PHYLUM II — PORIFERA — Sponges.

CHARACTERISTICS: Usually considered as diploblastic animals; body consists of a perforated (*inhalant pores*) cylinder, leading to central canal opening to outside through exhalant pore; peculiar flagellate, collared cells (*choanocytes*) typically present; body structure frequently complicated by budding; 2500 species.

CLASS I — CALCAREA — (*Grantia*).

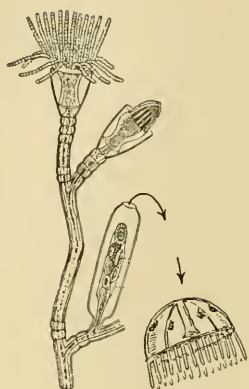
CHARACTERISTICS: Small marine sponges possessing one-, two-, or four-rayed calcareous spicules.

CLASS II — HEXACTINELLIDA — Deep-sea sponges (*Euplectella*).

CHARACTERISTICS: Sponges with six-rayed siliceous spicules.

CLASS III — DESMOSPONGIA — Finger sponge, bath sponge (*Chalina*, *Spongilla*, *Euspongia*).

CHARACTERISTICS: Diverse groups of sponges possessing spicules of silicon, not six-rayed, with spongin, or a combination of spicules and spongin.

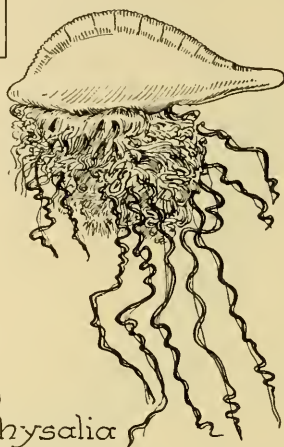


(1)
Obelia

Class I
Hydrozoa

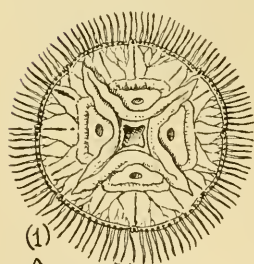


(2)
Hydra



(3)
Physalia
Portuguese man-of-war

COELENTERATA
jellyfishes, etc.



(1)
Aurelia

Class II
Scyphozoa



(1)
Metridium
sea anemone



(2)
Astrangia
coral

Class III
Anthozoa

PHYLUM III — COELENTERATA — Jellyfishes and corals.

CHARACTERISTICS: Mostly marine; radially symmetrical; diploblastic animals with a noncellular layer of mesoglea lying between; possessing tentacles, armed with nematocysts; body composed of a single gastrovascular cavity; 4500 species.

CLASS I — HYDROZOA — Fresh-water polyps, jellyfishes, and a few stony corals (*Hydra*, *Obelia*, *Physalia*).

CHARACTERISTICS: Mostly marine; usually hydroid and jellyfish forms occur in the same life cycle; the jellyfish (*medusae*) possess a shelflike velum extending inward from the margin toward the mouth (*manubrium*); a few species like *Hydra* possess no medusoid stage; the stony coral, *Millepora*, represents a colony with a coral-like skeleton of calcium carbonate.

CLASS II — SCYPHOZOA — (*Aurelia*).

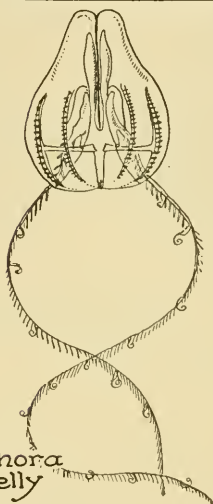
CHARACTERISTICS: Entirely marine, with the medusoid stage dominating; produced from subordinate polyp by terminal budding (*strobilation*); velum usually absent; lobate, typically eight-notched.

CLASS III — ANTHOZOA — Sea-anemones, sea-pens, and stony corals (*Metridium*, *Pennatula*, *Astrangia*, *Sagartia*).

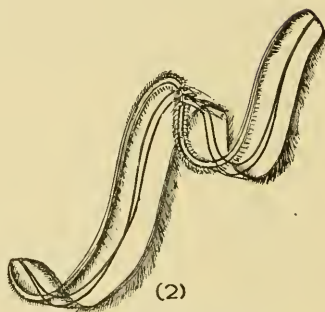
CHARACTERISTICS: Entirely marine with medusoid stage suppressed; organisms characterized by an introverted ectodermal mouth (*stomodaeum*) and vertical radiating mesenteries extending inward from the body wall; one, two, or more rarely three ciliated gullet grooves (*siphonoglyphs*) carry a stream of oxygenated water to interior. Corals produce islands and reefs; in addition they sometimes protect a shore from wave action.

CTENOPHORA

sea walnuts



(1)
Hormiphora
comb jelly



(2)
Cestus
Venus' girdle

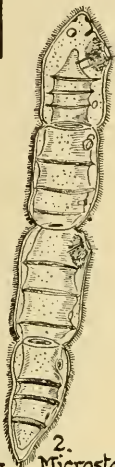
PHYLUM IV — CTENOPHORA — Sea-walnuts (*Cestus*, *Hormiphora*, *Mnemiopsis*).

CHARACTERISTICS: Eight radially arranged rows of comblike plates typically present; fundamentally bilaterally symmetrical; with a distinct mesodermal layer (therefore *triploblastic*); no nematocysts; 100 species.

Class I Turbellaria



1. Planaria



2. Microstomum

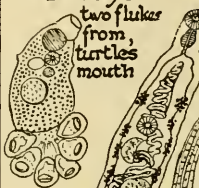
Class II Trematoda

1. Polystoma
two flukes
from
turtles
mouth

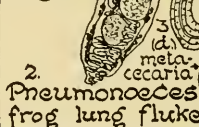
3 (a) egg



3 (b) miracidium



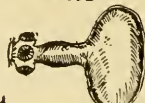
3 (c) cercaria

2. Pneumonoecus
frog lung fluke3. Clonorchis
liver fluke
of man

PLATYHELMINTHES FLATWORMS



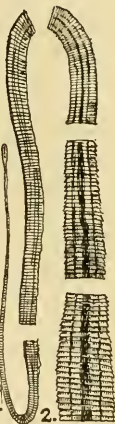
1 (a) Taenia



1 (b) cysticercus



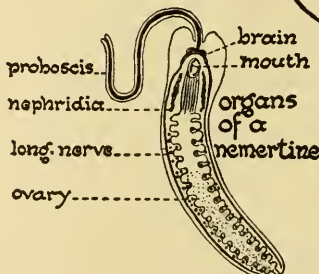
2 (a) proglottid

2. Diphylllobothrium
broad tapeworm
of man

Class III Cestoda



Micura



Class IV Nemertinea

PHYLUM V — PLATYHELMINTHES — Flatworms.

CHARACTERISTICS: Dorso-ventrally flattened, soft bodies, bilaterally symmetrical, animals lacking true segmentation and blood vascular system; no anus; excretory system of flame-cell type; only Class I free-living, all others parasitic; 4600 species.

CLASS I — TURBELLARIA — Free-living flatworms (*Planaria*, *Microstomum*, *Bdelloura*).

CHARACTERISTICS: Typically free-living, possessing a ciliated ectoderm; some ectodermal cells secrete mucus, or produce rodlike bodies (*rhabdites*); classification into orders depends upon nature of intestine.

CLASS II — TREMATODA — Flukes (*Polystoma*, *Pneumonoeces*, *Clonorchis*).

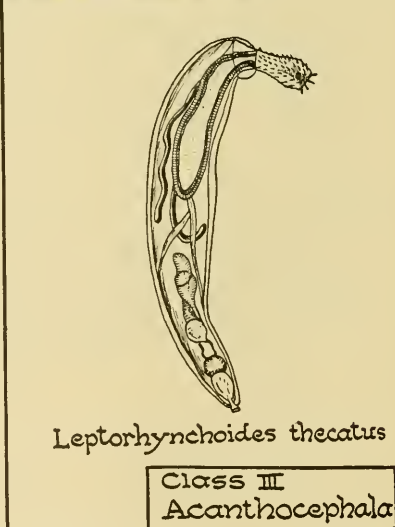
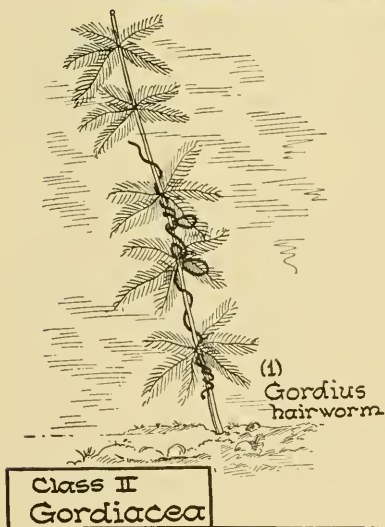
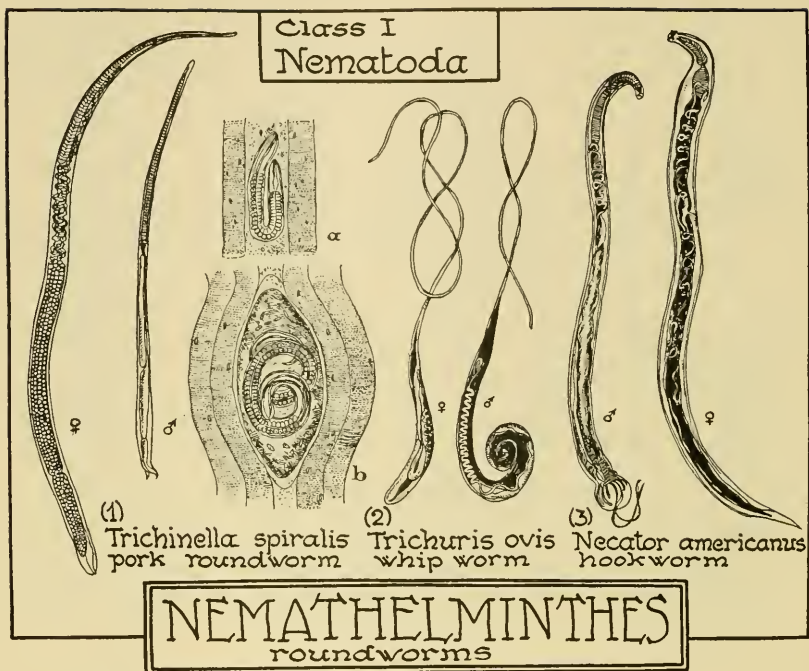
CHARACTERISTICS: Parasitic flatworms with non-ciliated ectoderm in the adult, possessing one or more suckers; highly specialized for parasitic existence; many are internal parasites having complicated life cycle, occupying as many as four hosts during development; digestive system present.

CLASS III — CESTODA — Tapeworms (*Taenia*, *Diphyllbothrium*).

CHARACTERISTICS: Members of this group are completely parasitic, living as adults in the alimentary canal of vertebrates; digestive tract absent; body typically divided into a chain of segments (*proglottids*), except for Cestodaria, budded from neck, gradually increasing in diameter towards posterior end; the head (*scolex*) typically bearing organs of adhesion in the form of hooks and suckers.

CLASS IV — NEMERTINEA — Nemertines (*Micrura*, *Cephalothrix*, *Cerebratulus*).

CHARACTERISTICS: Members of this group because of uncertain systematic position not always placed with the flatworms; characteristically found in moist earth or fresh water, most forms being marine; characterized by possessing alimentary canal with mouth and anus, definite blood-vascular system, and a long proboscis enclosed in a proboscis sheath.



PHYLUM VI — NEMATHELMINTHES — Roundworms.

CHARACTERISTICS: Bilaterally symmetrical; cylindrical, unsegmented, long and slender worms; usually a distinct alimentary canal with mouth and anus; primitive body cavity present; papillae or spines at anterior tip of body.

CLASS I — NEMATODA — Threadworms (*Trichinella*, *Trichuris*, *Necator*, *Oxyuris*).

CHARACTERISTICS: Members of this group are both free-living and parasitic on plants and animals; mouth usually terminal and alimentary canal composes a relatively straight tube with anal opening near posterior end of body; body cavity not lined by epithelium but bounded directly by muscles of the body; four thickenings of the ectoderm, one dorsal, one ventral, and two lateral, produce ridges containing excretory canals and nervous system; sexes separate.

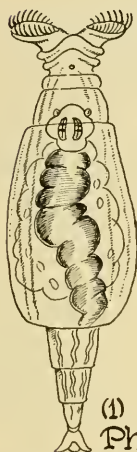
CLASS II — GORDIACEA — Hairworms (*Gordius*, *Paragordius*).

CHARACTERISTICS: Long, slender, and hairlike; free-living adults in water; larvae usually parasitize aquatic insect larvae (often Mayflies); usually reach a second host, as beetle or grasshopper, in which development continues; escape to water made by breaking through body wall; no lateral lines present; body cavity lined by distinct peritoneal epithelium derived from mesoderm; eggs discharged into body cavity instead of to outside.

CLASS III — ACANTHOCEPHALA — Spiny-headed worms (*Leptorhynchoides*, *Neoechinorhynchus*, *Macracanthorhynchus*).

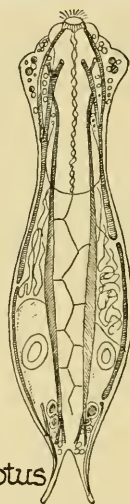
CHARACTERISTICS: Protrusible proboscis armed with hooks; alimentary canal absent; reproductive system complex; entirely parasitic, larval stage in Arthropods.

TROCHELMINTHES



(1)
Philodina
wheel animalcule

Class I
Rotifera



(1)
Chaetonotus

Class II
Gastrotricha

PHYLUM VII — TROCHELMINTHES — Rotifers, Gastrotricha.

CHARACTERISTICS: Small, frequently microscopic, identifiable by cilia around the mouth region; about 1300 species.

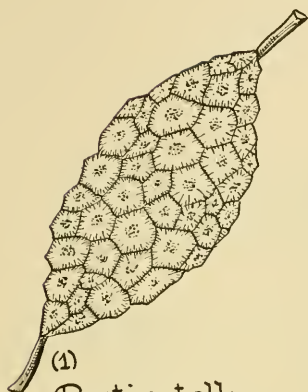
CLASS I — ROTIFERA — Wheel animalcules (*Philodina*, *Notommata*, *Trochosphaera*).

CHARACTERISTICS: Mostly free-living, inhabiting fresh water; distinct nervous system; universally characterized by presence of jaws inside pharynx (*mustax*); usually a foot.

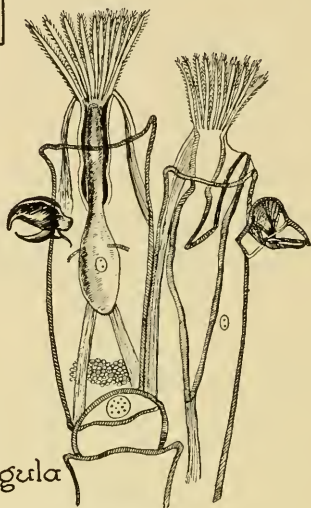
CLASS II — GASTROTRICHA — (*Chaetonotus*).

CHARACTERISTICS: Microscopic organisms reaching maximum length of about 0.5 mm.; animal divided into indistinct head, neck, and body; oral bristles on side of head; often a forked tail containing cement glands; locomotion by ciliary bands or by long bristles.

Class I
Bryozoa



(1)
Pectinatella
fresh-water bryozoan

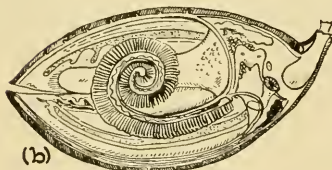


(2)
Bugula

MOLLUSCOIDEA
moss animals and lamp shells



(a)
external view



(b)
(1) Magellania

Class II
Brachiopoda



(1)
Phoronis

Class III
Phoronidea

PHYLUM VIII — MOLLUSCOIDEA — Moss animals and lamp-shells.

CHARACTERISTICS: Unsegmented, sessile, typically marine, bilaterally symmetrical animals possessing a ridge (*lophophore*) bearing ciliated tentacles which surrounds the mouth; 5700 species, including fossils.

CLASS I — BRYOZOA — Moss animals (*Electra*, *Pectinatella*, *Hemiseptella*, *Bugula*, *Plumatella*).

CHARACTERISTICS: Colonial, sessile, free-living animals; mostly marine; lophophore usually horseshoe-shaped; alimentary canal U-shaped; division into subclasses depends upon whether anus opens within or without lophophore.

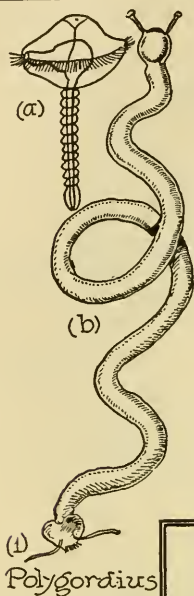
CLASS II — BRACHIOPODA — Lamp-shells (*Magellania*).

CHARACTERISTICS: Marine organisms possessing characteristic lophophore; body covered by calcareous, dorso-ventrally arranged bivalve shell, usually attached by a stalk (*peduncle*).

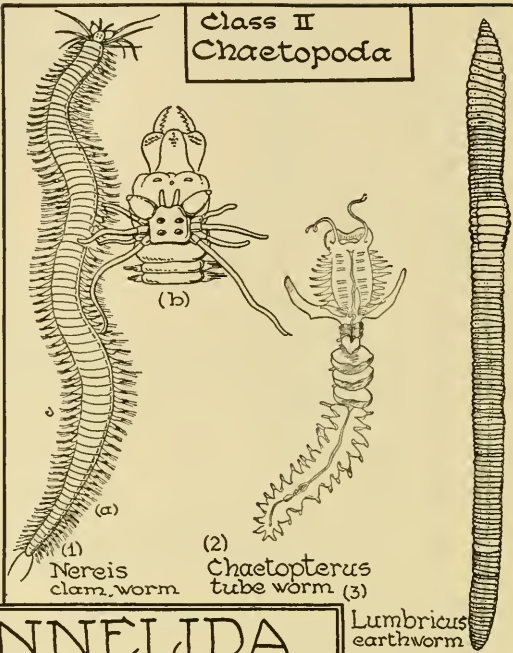
CLASS III — PHORONIDEA — (*Phoronis*).

CHARACTERISTICS: Small, marine, sedentary animals living in tubes; unsegmented adults are hermaphroditic, possessing a body cavity as well as characteristic horseshoe-shaped lophophore; two excretory organs and a vascular system.

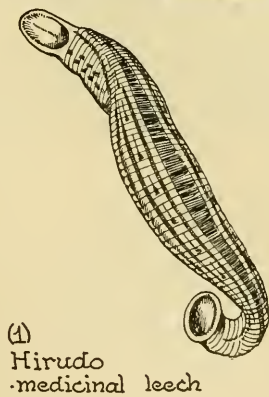
Class I Archannelida



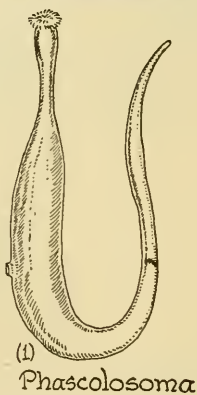
Class II Chaetopoda



ANNELIDA segmented worms



Class III Hirudinea



Class IV Gephyrea



Class V Chaetognatha

PHYLUM IX — ANNELIDA — Segmented worms.

CHARACTERISTICS: Segmented animals bearing distinct head, digestive tube, coelom, and sometimes nonjointed appendages; frequently supplied with chitinous bristles (*setae*); 6500 species.

CLASS I — ARCHIANNELIDA — (*Polygordius*).

CHARACTERISTICS: Marine worms lacking setae or parapodia; trochophore larvae present.

CLASS II — CHAETOPODA — Clam worms, tube worms, earthworms (*Nereis*, *Glycera*, *Chaetopterus*, *Lumbricus*).

CHARACTERISTICS: Members of this class marine, terrestrial, or fresh water; paired setae characteristically arranged in integumentary pits or upon parapodia; further subdivision based upon number of setae present: *Oligochaeta*, a few; *Polychaeta*, many.

CLASS III — HIRUDINEA — Leeches (*Hirudo*, *Glossiphonia*).

CHARACTERISTICS: Hermaphroditic, dorso-ventrally flattened annelids with 32 body segments, two suckers, one surrounding mouth, the other the posterior end; setae and parapodia absent; growth of mesenchymatous cells reduces coelom.

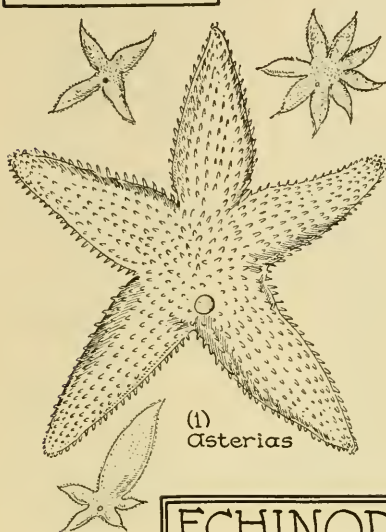
CLASS IV — GEPHYREA — *Sipunculid* worms (*Phascolosoma*).

CHARACTERISTICS: Non-segmented when adult, without setae or parapodia; characterized by a large coelom and trochophore larvae.

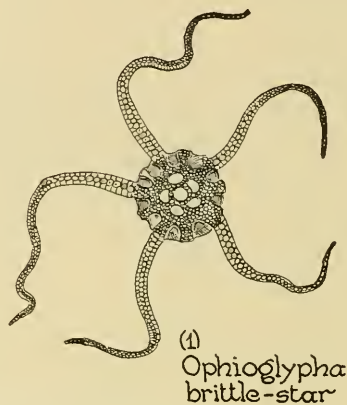
CLASS V — CHAETOGNATHA — Arrow worms (*Sagitta*).

CHARACTERISTICS: Small, transparent, marine invertebrates with well-developed body cavity, alimentary canal, nervous system, two eyes; lobes on sides of mouth armed with bristles which aid in capturing food.

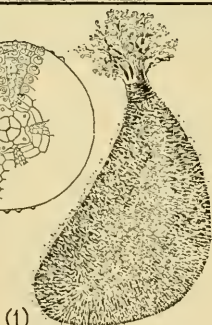
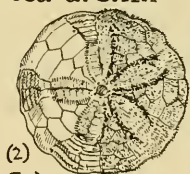
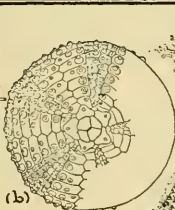
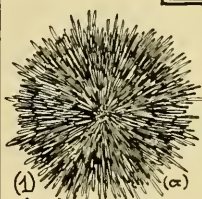
Class I
Asteroidea



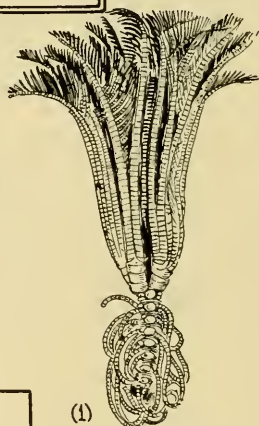
Class II
Ophiuroidea



ECHINODERMATA
starfishes, etc.



Class IV
Holothuroidea



Class III
Echinoidea

Class V
Crinoidea

PHYLUM X — ECHINODERMATA — Starfishes, sea-urchins, sea-cucumbers.

CHARACTERISTICS: Adults radially symmetrical (pentamerous); marine; tube-feet, water vascular system, distinct alimentary canal, large body cavity usually present; frequently a spiny skeleton of calcareous plates; larvae bilaterally symmetrical; 4800 species.

CLASS I — ASTEROIDEA — Starfishes (*Asterias*, *Mediaster*).

CHARACTERISTICS: Typically five rays or arms not marked off from central disk; each ray possessing ventral ambulacral groove through which numerous tube-feet extend; gastric pouches and hepatic caeca extend into rays; blunt spines and pedicellariae present; respiration by dermal branchiae.

CLASS II — OPHIUROIDEA — Brittle-stars (*Ophiopholis*, *Ophiothrix*, *Ophioglypha*, *Ophioderma*).

CHARACTERISTICS: Typically pentamerous with arms sharply marked off from disk; no ambulacral groove; hepatic caeca and anal opening lacking.

CLASS III — ECHINOIDEA — Sea-urchins, sand-dollars, spatangoids (*Arbacia*, *Strongylocentrotus*, *Echinarachnius*, *Spatangus*, *Möira*).

CHARACTERISTICS: Typically pentamerous without arms or free rays; test of calcareous plates bears movable spines; pedicellariae usually three-jawed; mouth with five conspicuous teeth constituting part of Aristotle's lantern.

CLASS IV — HOLOTHUROIDEA — Sea-cucumbers (*Holothuria*, *Thyone*, *Leptosynapta*).

CHARACTERISTICS: Long, ovoid, soft-bodied echinoderms; tentacles about mouth; body wall muscular; skeleton greatly reduced.

CLASS V — CRINOIDEA — Sea-lilies or feather-stars (*Antedon*, *Hathrometra*, *Comactinia*, *Pentacrinus*).

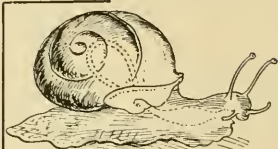
CHARACTERISTICS: Usually five branched arms, possessing featherlike divisions (pinnules); aboral pole sometimes possessing cirri but more generally a stalk for temporary or permanent attachment; a few modern types, most forms known as fossils.

Class I
Amphineura



(1)
Ischnochiton
chiton

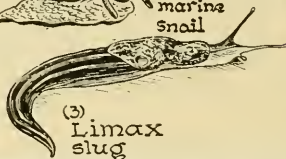
Class II
Gastropoda



(1)
Helix
land snail

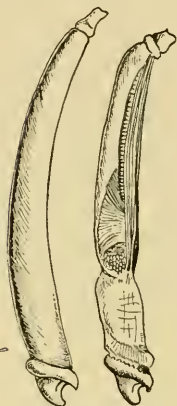


(2) Busycon
marine
snail



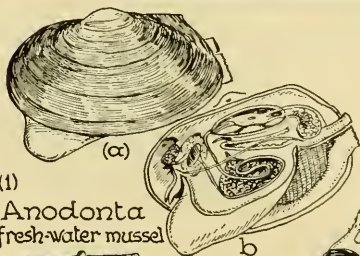
(3)
Limax
slug

Class III
Scaphopoda

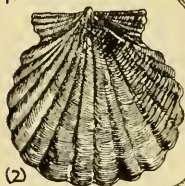


(1)
Dentalium
tooth snail

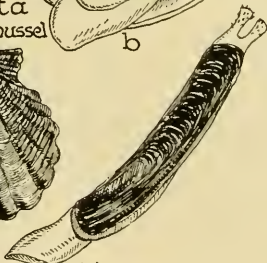
MOLLUSCA
clams, snails, etc



(1)
Anodonta
fresh-water mussel

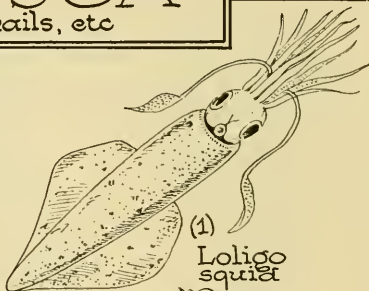


(2)
Pecten
scallop



(3)
Ensis
razor-shell clam

Class IV
Pelecypoda



(1)
Loligo
squid



(2)
Polypus
octopus

Class V
Cephalopoda

PHYLUM XI — MOLLUSCA — Snails, clams, and oysters.

CHARACTERISTICS: Unsegmented, bilaterally symmetrical, triploblastic animals bearing a shell, muscular foot, and mantle; four main pairs of nervous ganglia; 70,000 species.

CLASS I — AMPHINEURA — Chitons (*Chaetopleura*, *Ischnochiton*).

CHARACTERISTICS: Bilaterally symmetrical; shell typically composed of eight transverse calcareous plates with many pairs of gill filaments.

CLASS II — GASTROPODA — Snails, slugs, whelks (*Limax*, *Physa*, *Helix*, *Lymnaea*, *Campeloma*, *Busycon*).

CHARACTERISTICS: Asymmetrical animals with well-developed head; spirally-coiled shell.

CLASS III — SCAPHOPODA — Elephant's-tusk shells (*Dentalium*, *Siphonodentalium*).

CHARACTERISTICS: Both shell and mantle tubular; protrusible foot; rudimentary head.

CLASS IV — PELECYPODA — Clams, mussels, oysters, and scallops (*Ensis*, *Anodonta*, *Venus*, *Teredo*, *Ostrea*, *Pecten*).

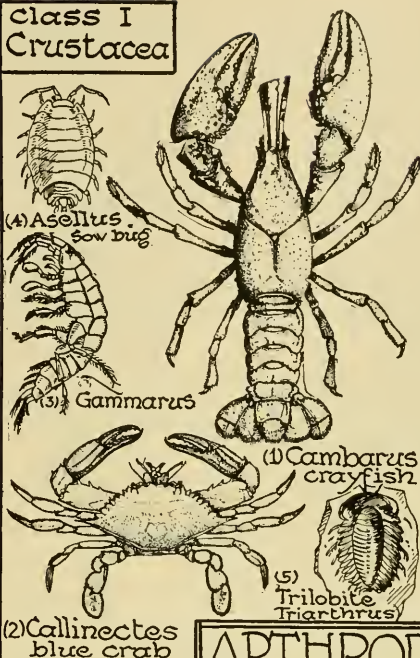
CHARACTERISTICS: Usually bivalved shells with two-lobed mantle; no head; body laterally compressed; bilaterally symmetrical.

CLASS V — CEPHALOPODA — Squids, cuttlefishes, octopus, nautilus (*Loligo*, *Polypus*, *Dosidicus*).

CHARACTERISTICS: Bilaterally symmetrical; with foot divided into siphon and arms provided with suckers; well-developed nervous system concentrated in head; mouth possesses strong jaws.



Class I Crustacea

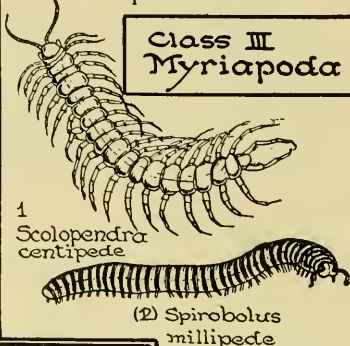


Class II Onychophora

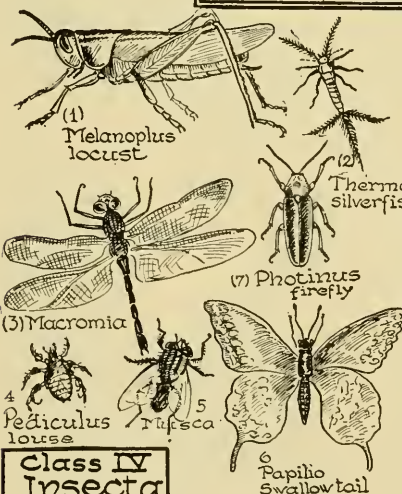


1 Peripatus

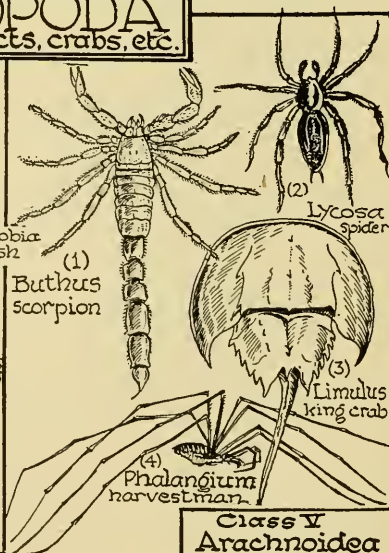
Class III Myriapoda



ARTHROPODA spiders, insects, crabs, etc.



Class IV Insecta



Class V Arachnoidea

PHYLUM XII — ARTHROPODA — Lobsters, crabs, spiders, millipedes, insects.

CHARACTERISTICS: External evidence of segmentation, body at least being divisible into a well-defined head, thorax, and abdomen; jointed appendages; chitinous exo-skeleton; nervous system of ladder type with tendency toward concentration in head region; main longitudinal blood vessel with heart dorsal to alimentary canal; coelom reduced; body cavity filled with blood (hemocoel); 640,000 species.

CLASS I — CRUSTACEA — Crayfish, crabs, water fleas, barnacles, sowbugs (*Cambarus*, *Callinectes*, *Gammarus*, *Asellus*, *Triarthrus*).

CHARACTERISTICS: Mostly aquatic; usually bearing gills; with two pairs of antennae (feelers); chitinous exo-skeleton; body divided into head, thorax, and abdomen; head and thorax sometimes fused (*cephalothorax*); further subdivision depending largely upon characteristics of carapace.

CLASS II — ONYCHOPHORA — Annelidlike arthropods (*Peripatus*).

CHARACTERISTICS: Tropical, primitive, wormlike types presumably intermediate between the segmented worms and the arthropods; excretory system of annelid type (nephridial); respiratory organ resembles tracheae of insect group; external appendages ringed, suggesting segmentation of arthropods.

CLASS III — MYRIAPODA — Centipedes and millipedes (*Scolopendra*, *Spirobolus*).

CHARACTERISTICS: Body relatively long and definitely metameric; one pair of antennae; appendages segmented; legs similar; respiratory system of tracheal type; in millipedes there are two pairs of legs per somite, in centipedes one.

CLASS IV — INSECTA — Insects, as butterflies, grasshoppers, beetles, bees.

CHARACTERISTICS: Usually possess wings; one pair of antennae; tracheal respiratory system; segmented legs.

Order 1 — *Thysanura* — Bristletails, Silverfish (*Lepisma*, *Campodea*, *Thermobia*).

CHARACTERISTICS: Wingless arthropods; primitive; probably derived from wingless ancestors; 11 abdominal segments; chewing mouth parts; usually two or three long, threadlike, segmented caudal appendages; less than 20 species in the United States; no metamorphosis.

Order 2 — *Collembola* — Springtails (*Archorutes*).

CHARACTERISTICS: Primitive wingless insects with chewing or sucking mouth parts; four segmented antennae; usually no tracheae; six abdominal segments; a springing organ (*furcula*) present on ventral side of fourth abdominal segment in most species; no metamorphosis.

Order 3 — *Orthoptera* — Grasshoppers, cockroaches, walking sticks (*Melanoplus*, *Periplaneta*, *Diapheromera*).

CHARACTERISTICS: Members of this order are characterized by two pairs of wings (sometimes greatly reduced); the fore wings usually thickened, sometimes leathery; hind wings folded fanlike beneath fore wings; biting mouth parts; gradual or simple metamorphosis.

Order 4 — *Isoptera* — Termites or white ants (*Reticulitermes*).

CHARACTERISTICS: Four similar wings lying flat on back when at rest; workers are wingless; chewing mouth parts; abdomen joined directly to thorax; gradual or simple metamorphosis.

Order 5 — *Neuroptera* — Dobson flies, alder flies, lacewings, ant-lions (*Corydalid*, *Chrysopa*, *Myrmeleon*).

CHARACTERISTICS: Four membranous wings with many veins; chewing mouth parts; larvae carnivorous; tracheal gills usually present on aquatic larvae; the larvae of the horned *Corydalid* known as hellgrammites are used by fishermen as bait; complete metamorphosis.

Order 6 — *Ephemera* — Mayflies (*Ephemera*).

CHARACTERISTICS: Mouth parts of adult vestigial; two pairs of membranous, more or less triangular, wings; fore wings larger than hind wings; caudal filaments and cerci very long; aquatic larvae breathe by tracheal gills, usually located on either side of abdomen; adult's span of life short; mouth parts poorly developed, probably making organism incapable of taking food; nymph remains one to three years in water; adults moult within 24 hours after acquiring wings, therefore called sub-imago; gradual or simple metamorphosis.

Order 7 — *Odonata* — Dragonflies and damsel flies (*Macromia*, *Agrion*).

CHARACTERISTICS: Chewing mouth parts; two pairs of membranous veined wings; characteristic joint (nodus) on anterior margin of each wing; eyes large, compound; nymphs are aquatic; gradual or simple metamorphosis. When at rest dragonflies hold their wings horizontally and at right angles to body, while damsel flies maintain theirs vertically.

Order 8 — *Plecoptera* — Stone flies (*Allopnia*, *Taeniopteryx*).

CHARACTERISTICS: Chewing mouth parts often poorly developed in adults; two pairs of wings; hind wings usually larger and folded beneath fore wings; nymphs aquatic, bearing filamentous tracheal gills; usually beneath stones in flowing water; gradual or simple metamorphosis. The salmon fly, *Taeniopteryx pacifica*, is a dangerous pest in the State of Washington because it destroys buds.

Order 9 — *Corrodentia* — Book- and bark-lice (*Troctes*).

CHARACTERISTICS: Either wingless, or two pairs of membranous wings characterized by a few prominent veins; fore wings larger than hind wings; when at rest held over body like sides of a roof; chewing mouth parts; gradual metamorphosis. Book-lice often eat paper and bindings of old books.

Order 10 — *Mallophaga* — Chewing lice or bird-lice (*Menopon*, *Trichodectes*).

CHARACTERISTICS: Chewing mouth parts; wings absent; eyes degenerate; metamorphosis gradual or wanting. Members of this group are ectoparasitic upon hair and scales of birds and mammals.

Order 11 — *Embiidina* — *Embiids* (*Embia*).

CHARACTERISTICS: Chewing mouth parts; wingless or possessing two pairs of delicate membranous wings with few veins; cerci present on two segments; males usually winged, females wingless; gradual metamorphosis. These organisms live under stones, etc., in tunnels formed of silk produced in tarsal glands.

Order 12 — *Thysanoptera* — Thrips (*Thrips*, *Franklinella*, *Cryptothrips*).

CHARACTERISTICS: Piercing mouth parts; either wingless or with two pairs of long, narrow membranous wings, practically veinless; large, free prothorax; feet clawless but possessing small protrusible membranous suckers for clinging; many parthenogenetic; gradual metamorphosis.

Order 13 — *Anoplura* — Sucking lice (*Pediculus*, *Phthirus*).

CHARACTERISTICS: Wingless ectoparasitic lice with piercing and sucking mouth parts; eyes poorly developed or absent; parasitic on bodies of mammals; gradual metamorphosis. At least two species, the head louse and crab louse, occur on man.

Order 14 — *Hemiptera* — True bugs (*Artocorixa*, *Lethocercus*).

CHARACTERISTICS: Either wingless, or with two pairs of wings; in such cases fore wings are thickened at base; mouth parts adapted for piercing and sucking; gradual or simple metamorphosis. Members of this group contain many interesting and sometimes economically important forms. The water-boatmen (*Corixidae*) have long, flat, fringed metathoracic legs which are adapted for swimming. These peculiar forms carry a film of air about body when under water. The leaf bugs (*Neridae*) are frequently numerous and injurious to plants. Bedbugs (*Cimicidae*) have been accused of transmitting various diseases. The cabbage bug does damage to garden vegetables.

Order 15 — *Homoptera* — Cicadas, aphids, leaf-hoppers, and scales (*Euscelis*, *Empoasca*, *Rhopalosiphum*).

CHARACTERISTICS: Mouth parts adapted for piercing and sucking; two pairs of wings of uniform thickness held over back like sides of a roof. The cicadas (*Cicadidae*) are better known as the "seventeen-year locust." Plant-lice (*Aphididae*) are mostly small green insects that suck juices from plants and have a gradual metamorphosis.

Order 16 — *Dermaptera* — Earwigs (*Anisolabis*, *Labia*).

CHARACTERISTICS: Either wingless, or possessing one or two pairs of wings, in such cases fore wings are small and leathery, meeting in straight line along back; chewing mouth parts; gradual metamorphosis. Earwigs are nocturnal and feed principally upon vegetation.

Order 17 — *Coleoptera* — Beetles and weevils (*Hydrous*, *Dytiscus*, *Photinus*, *Anthonomus*).

CHARACTERISTICS: Either wingless or with two pairs of wings, fore wings being hard and sheathlike (*elytra*); hind wings membranous and are folded two ways under elytra; large movable prothorax; chewing mouth parts; complete metamorphosis. Many forms are found in this group, as the tiger beetles, fireflies, click beetles, whirligig, ladybird, and leaf beetles.

Order 18 — *Strepsiptera* — Stylopedes (*Xenos*).

CHARACTERISTICS: Mouth parts reduced or wanting; nutrition by absorption; males possessing club-shaped fore wings and large membranous hind wings; females wingless and legless; life cycle complex; parasitic on bees, wasps, and homopterous bugs.

Order 19 — *Mecoptera* — Scorpion-flies (*Panorpa*, *Bittacus*).

CHARACTERISTICS: Members of this group are wingless or characterized by two pairs of long membranous wings containing many veins; head prolonged into beak; antennae long and slender; mouth parts adapted for chewing; males with clasping-organ on caudal extremity resembling sting of a scorpion; metamorphosis complete.

Order 20 — *Trichoptera* — Caddis flies (*Phryganea*, *Molanna*).

CHARACTERISTICS: Adults with vestigial mouth parts; two pairs of membranous wings obscurely colored by long silky hairs and narrow scales; antennae long and slender; metamorphosis complete; larvae and pupae aquatic, constructing portable cases of sand grains or vegetable debris fastened together with silk from modified salivary glands.

Order 21 — *Lepidoptera* — Butterflies and moths (*Tinea*, *Alsophila*, *Papilio*).

CHARACTERISTICS: Wingless, or with two pairs of membranous wings covered with overlapping scales; sucking mouth parts coiled beneath head consist of two maxillae fastened to form a tube; metamorphosis complete; larvae known as caterpillars; many species known.

Order 22 — *Diptera* — Flies and mosquitoes (*Tipula*, *Culex*, *Prosimulium*, *Musca*, *Drosophila*).

CHARACTERISTICS: One pair of membranous fore wings on mesothorax, or wingless; knobbed threads (*halteres*) on metathorax represents hind wings; mouth adapted for piercing and sucking, forming proboscis; larvae known as maggots; complete metamorphosis.

Order 23 — *Siphonaptera* — Fleas (*Ctenocephalus*, *Pulex*).

CHARACTERISTICS: Wingless insects with laterally compressed body; head small; no compound eyes; mouth adapted for piercing and sucking, legs for leaping; metamorphosis complete; ectoparasites of mammals and more rarely birds.

Order 24 — *Hymenoptera* — Saw flies, ichneumon flies, ants, wasps, and bees (*Cladius*, *Ophion*, *Formica*, *Vespa*, *Apis*).

CHARACTERISTICS: Wingless or with two pairs of membranous wings; fore wings usually larger; venation reduced; wings held together on each side by hooks (*hamuli*); mouth parts adapted for chewing or sucking; first abdominal segment fused with thorax; complete metamorphosis.

CLASS V — ARACHNOIDEA — Spiders, scorpions, ticks, mites, and king crabs (*Caddo*, *Lycosa*, *Phalangium*, *Buthus*, *Argas*, *Sarcoptes*, *Limulus*).

CHARACTERISTICS: No antennae nor true jaws; two of six pairs of jointed appendages modified for mouth parts; respiration by lung-books or tracheae; first pair of appendages usually contain poison glands, second pair used as jaws; terminal portions as sensory organs; body usually divided into anterior cephalothorax and posterior abdomen; former bears four pairs of legs for locomotion.

THE ANIMAL KINGDOM¹

PHYLUM	CLASS	EXAMPLES	ESTIMATED NUMBER OF LIVING SPECIES DESCRIBED	
Chordata	VERTEBRATES			
	Mammalia	Man, cat, horse, bat, whale	3,750	38,000
	Aves	Birds, fowls	13,500	
	Reptilia	Turtles, snakes, lizards, alligators	1,000	
	Amphibia	Frogs, toads, salamanders	1,750	
	Pisces	Fishes	13,500	
	Minor Classes	Tunicates, Balanoglossus, etc.	1,500	
	Total Chordata			
Arthropoda	INVERTEBRATES			
	Onychophora		70	675,000
	Crustacea	Crayfish, crabs, water fleas, barnacles, sowbugs	20,000	
	Myriapoda	Centipedes, millipedes, etc.	2,430	
	Insecta	All true insects	625,000	
	Arachnoidea	Spiders, scorpions, ticks, mites, and king crabs	27,500	
	Total Arthropoda			
	Mollusca	Snails, slugs, clams, oysters	80,000	
Echinodermata	Starfish, sand dollar, sea-urchin	5,000		
Annelida (Annulata)	Earthworm, leeches	5,000		
Molluscoidea	Bryozoa, brachiopods	2,500		
Platyhelminthes	Flatworms, flukes, tapeworms	6,500		
Nemathelminthes	Roundworms, Trichinella, Filaria	3,500		
Trochelminthes	Rotifers, wheel animalcules	1,500		
Coelenterata	Jelly-fishes, coral animals, Hydra	5,000		
Porifera	Sponges	3,000		
Protozoa	Ameba, Paramecium, Euglena, malarial organisms, trypanosomes	15,000		
Grand total			840,000	

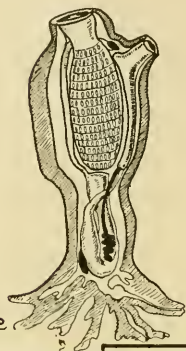
¹ Modified from Metcalf and Flint, *Destructive and Useful Insects*. By permission of the McGraw-Hill Book Company, publishers. The discrepancies between this table and the text illustrate the pragmatic nature of taxonomy.

sub-phylum I
HEMICHORDATA
half-a-chord



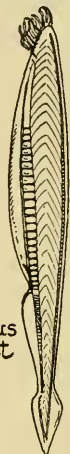
(1) Balanoglossus

sub-phylum II
UROCHORDATA
chord-in-tail



(1) Tunicate

sub-phylum III
CEPHALOCHORDATA
chord-in-head



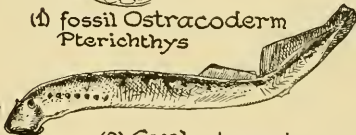
(1) Amphioxus lancelet

sub-phyla of the
CHORDATA
animals with a notochord

(A) SUPERCLASS AGNATHA



(1) fossil Ostracoderm Pterichthys



(2) Cyclostomata
Petromyzon lamprey

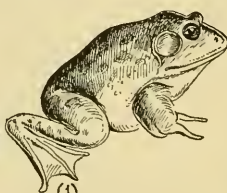
(B) SUPERCLASS PISCES



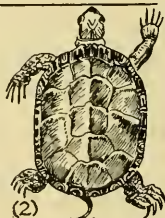
(1) fishes

sub-phylum IV
VERTEBRATA
with backbones

(C) SUPERCLASS TETRAPODA



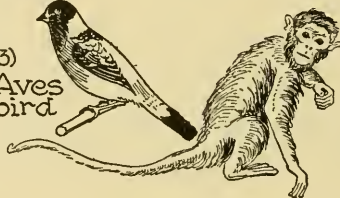
(1) Amphibia frog



(2) Reptilia turtle



(3) Aves bird



(4) Mammalia mammals

PHYLUM XIII — CHORDATA — Animals with notochord.

CHARACTERISTICS: All possess a dorsal supporting rod or notochord and pharyngeal gill clefts at some stage in life cycle; tubular nerve cord dorsal to digestive tract; 36,000 species.

Sub-Phylum I — Hemichordata — (*Balanoglossus*).

CHARACTERISTICS: Wormlike marine organisms of doubtful relationship that burrow in sand and resemble the larval echinoderms in development; head-end with proboscis and collar; with or without a notochord.

Sub-Phylum II — Urochordata — *Tunicates* and ascidians.

CHARACTERISTICS: Marine organisms with saclike covering (*tunic*); larvae resemble tadpoles, possessing notochord in tail; gill slits and endostyle present in pharynx.

Sub-Phylum III — Cephalochordata — Lancelets (*Amphioxus*).

CHARACTERISTICS: Segmented primitive chordates, burrowing in sand; laterally compressed; notochord extending from anterior tip to tail.

Sub-Phylum IV — Vertebrata (or Craniata) — Vertebrates.

CHARACTERISTICS: Animals with definite head, sense organs, closed circulatory system, and axial notochord at some period in life cycle; skull and vertebral column present either in cartilaginous or bony stage.

SUPER-CLASS A — AGNATHA — Fossil, armored Ostracoderms, lampreys and hagfishes (Cyclostomata). Primitive fishlike forms (*Pterichthys*, *Petromyzon*).

CHARACTERISTICS: Animals without jaws; sucking mouth and primitive brain present.

SUPER-CLASS B — PISCES — True fishes.

CHARACTERISTICS: Organisms with true jaws; typically scaled; characteristically aquatic; appendages developed into fins; two-chambered heart.

Class I
Elasmobranchii

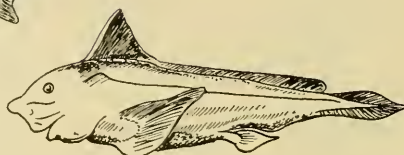


(1)
Squalus
shark



(2)
Raia
ray

Class II
Holocephali

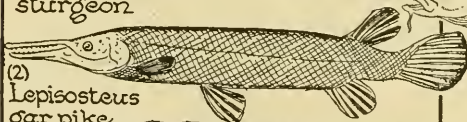


(1)
Chimaera
spook fish

(B) Superclass PISCES
FISHES PROPER



(1)
Acipenser
sturgeon



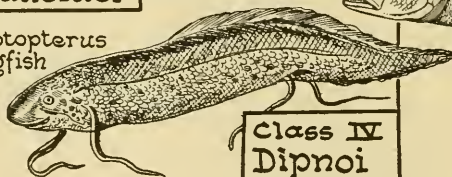
(2)
Lepisosteus
gar pike



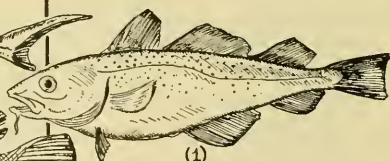
(3)
Polypterus

class III
Ganoidei

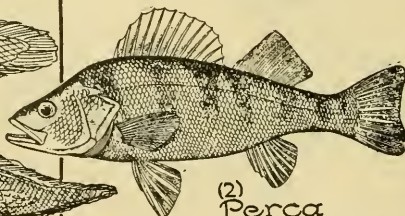
(1)
Protopterus
lungfish



Class IV
Dipnoi



(1)
Gadus
codfish



(2)
Perca
yellow perch

class V
Teleostei

CLASS I — ELASMOBRANCHII — Gristle-fishes (*Squalus*, *Raia*).

CHARACTERISTICS: Cold-blooded fishlike vertebrates with jaws; characterized by a cartilaginous skeleton, persistent notochord and placoid scales; upper jaw suspended to cranium indirectly by means of ligaments and cartilages (hyostylic).

CLASS II — HOLOCEPHALI — Elephant-fishes (*Chimaera*).

CHARACTERISTICS: Immovable upper jaw fused with cranium (autostylic) resembling higher forms; gill slits covered by flap (*operculum*); tail heterocercal.

CLASS III — GANOIDEI — Enamel-scaled fishes (*Acipenser*, *Lepisosteus*, *Polyp-terus*).

CHARACTERISTICS: More or less armored fish; remnants of group dominant in Devonian seas; degenerating spiral valve in intestine associated with presence of pyloric caeca; scales usually rhomboidal, fitting together rather than overlapping; dorsal fin usually close to caudal fin.

CLASS IV — DIPNOI — Lung-fishes (*Neoceratodus*, *Lepidosiren*, *Protopterus*).

CHARACTERISTICS: Semitropical fishes, passing dry season by aestivating in slimy cocoon; during period of active life use gills, and while aestivating breathe air, the modified swim bladder acting as a lung; cycloid scales; auricle of heart partially divided.

CLASS V — TELEOSTEI — Bony fishes (*Ctenolabrus*, *Perca*, *Gadus*, *Micropterus*).

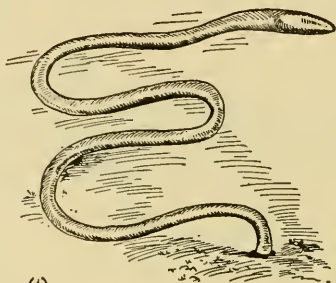
CHARACTERISTICS: Bony fishes, breathing primarily by gills; well-developed operculate bones, cycloid or ctenoid scales; tail homocercal. These fishes constitute about 90 per cent of all known varieties.

Order (1)
Stegocephalia
 fossil amphibia



Restorations
 of extinct
 Stegocephali

Order (2)
Apoda
 legless amphibia

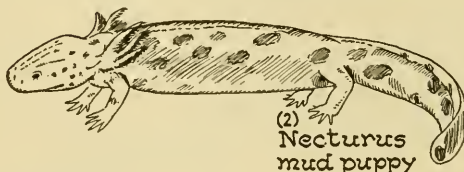


(1)
Caecilia
 "blind" wormlike
 amphibian

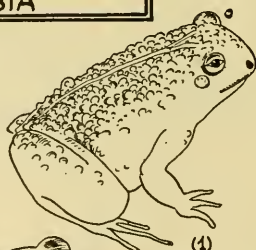
(C) Superclass **TETRAPODA**
 CLASS I AMPHIBIA



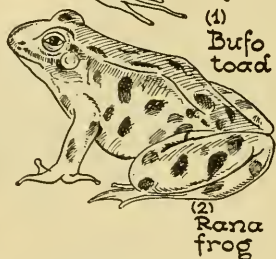
(1)
Triturus
 spotted newt



(2)
Necturus
 mud puppy



(1)
Bufo
 toad



(2)
Rana
 frog

Order (3)
Urodela
 amphibia with tails

Order (4)
Anura
 tailless amphibia

SUPER-CLASS C — TETRAPODA — Four-footed vertebrates.

CHARACTERISTICS: Well-defined limbs with hands and feet typically constructed on plan of five digits; stapes or columella present in ear; girdles adapted to bear weight on land; body divisible into neck and trunk, tail present.

CLASS I — AMPHIBIA — Frogs and salamanders.

CHARACTERISTICS: Cold-blooded, naked vertebrates undergoing a metamorphosis; usually with five-fingered limbs (pentadactylous); young usually aquatic, breathing by gills; adults using lungs and skin, usually air breathers.

Order 1 — Stegocephalia — Extinct fossil amphibians (Eryops, Loxomma).

CHARACTERISTICS: Fossil forms resembling amphibia, flourishing in carboniferous age; probably earliest four-footed air breathers.

Order 2 — Apoda — Legless amphibia (Herpeles, Siphonops, Caecilia).

CHARACTERISTICS: Small, tropical, wormlike, often blind amphibia, burrowing in ground.

Order 3 — Urodela — Salamanders (Desmognathus, Necturus, Cryptobranchus, Triturus).

CHARACTERISTICS: Tadpole-like tail retained throughout life; some never emerge from water; a few retain external gills in adult stage.

Order 4 — Anura — Frogs and toads (Rana, Bufo, Hyla).

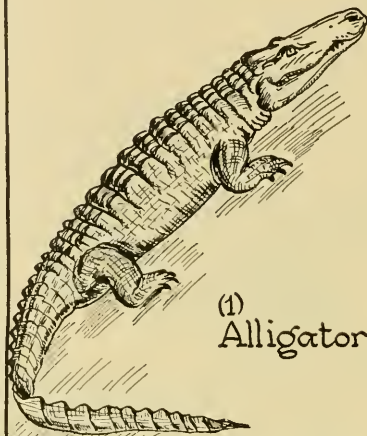
CHARACTERISTICS: Tailless upon completing their metamorphosis; capable of singing; characterized by the possession of movable eyelids.

Order 1
Rhynchocephalia
"the old timers"



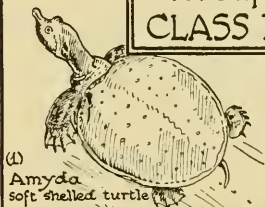
(1)
Sphenodon
three-eyed
lizard

Order 2
Crocodylia
crocodiles, alligators



(1)
Alligator

(C) Superclass TETRAPODA
CLASS II REPTILIA



(1)
Amyda
soft-shelled turtle



(2)
Eretmochelys
hawk's bill turtle



(3)
Terrapene
box turtle

Order 3
Chelonina
turtles, tortoises

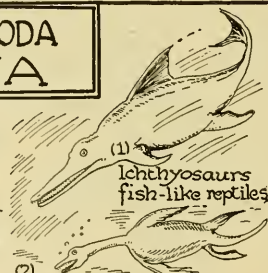


(1)
sub order Sauria
lizards



(2)
sub order Serpentes
snakes

Order 4
Squamata
snakes, lizards



(2)
Plesiosaurs



(3)
Pterodactyls
flying reptiles



(4)
Dinosaurs
giant reptiles

Orders 5-8 fossil reptiles
Ichthyosauria, Plesiosauria,
Pterodactylia, Dinosauria

CLASS II — REPTILIA — Turtles, snakes, alligators, and lizards.

CHARACTERISTICS: Cold-blooded; usually covered with scales and frequently bony plates; air breathers.

Order 1 — *Rhynchocephalia* — "The old-timers," *Sphenodon*.

CHARACTERISTICS: Biconeave vertebrae often containing remnants of notochord; quadrate bone immovable; parietal eye present. This group is represented by one genus of lizards, *Sphenodon*, found only in New Zealand.

Order 2 — *Crocodylia* — Crocodiles and alligators (*Crocodylus*, *Alligator*).

CHARACTERISTICS: Anterior appendages bearing five digits, posterior four with trace of fifth; longitudinal slit constitutes cloacal opening; vertebrae procoelous.

Order 3 — *Chelonia* — Turtles and tortoises (*Amyda*, *Eretmochelye*, *Terrapene*, *Testudo*, *Chelonia*).

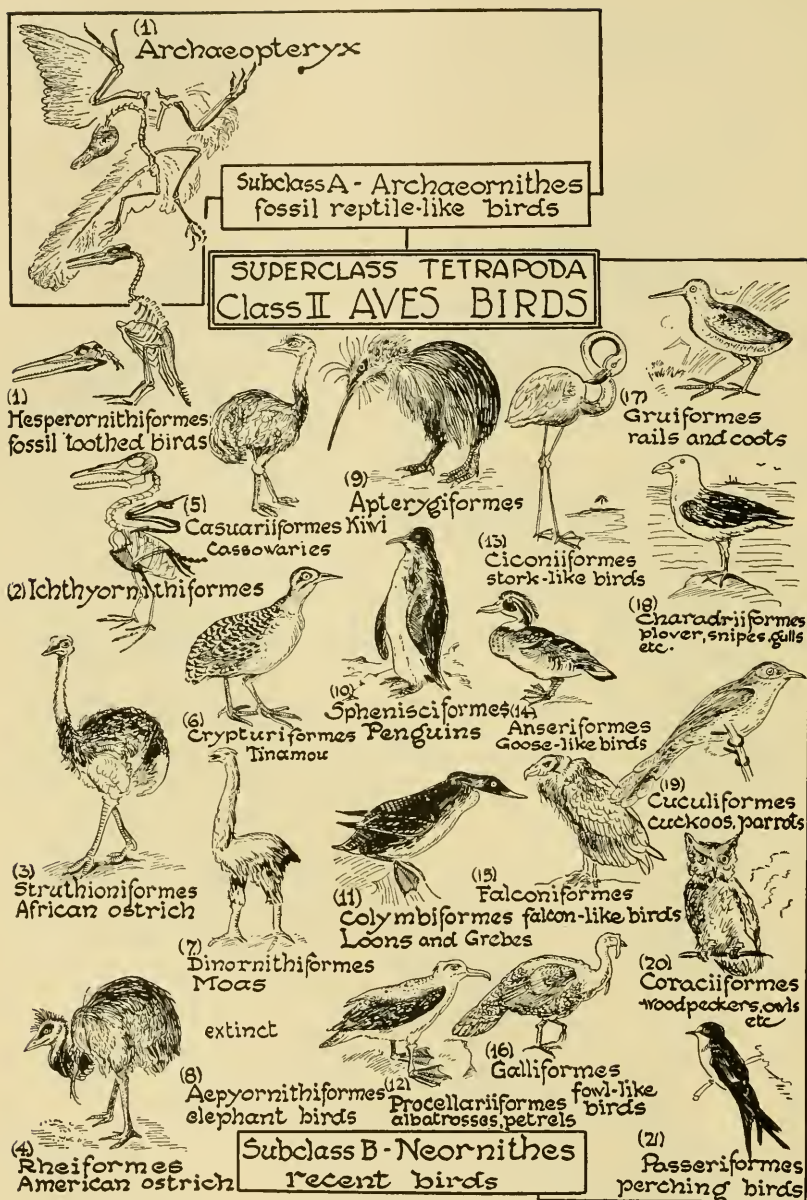
CHARACTERISTICS: Body surrounded by bony case forming a carapace and plastron; toothless jaws; immovable quadrate bone; appendages typically with five digits.

Order 4 — *Squamata* — Snakes and lizards (*Phrynosoma*, *Heloderma*, *Thamnophis*).

CHARACTERISTICS: Usually with horny epidermal scales or plates; movable quadrate bone; vertebrae usually procoelous; ribs with single heads. This order is usually subdivided into two sub-orders: lizards (*Sauria*); and snakes (*Serpentes*).

Orders 5-8 — *Dinosauria* — Fossil reptiles (*Ichthyosaurs*, *Plesiosaurs*, *Pterodactyls*, *Dinosaurs*).

In these groups belong such forms as the fishlike reptiles (*Ichthyosaurs*); the long-necked reptiles (*Plesiosaurs*); the flying reptiles (*Pterodactyls*); and the giant reptiles (*Dinosaurs*).



CLASS III — AVES — Birds.

CHARACTERISTICS: Typically feathered and toothless; warm-blooded.

SUBCLASS A — ARCHAEOORNITHES — Fossil birds (*Archaeopteryx*).

CHARACTERISTICS: Ancient reptilelike fossil birds; only three specimens of a single genus (*Archaeopteryx*) are known.

SUBCLASS B — NEORNITHES — Recent birds.

CHARACTERISTICS: Mostly composed of birds which are represented by living forms; 21 orders.

Order 1 — *Hesperornithiformes* — (*Hesperornis*).

CHARACTERISTICS: Fossil, toothed birds from America; teeth set in a groove.

Order 2 — *Ichthyornithiformes* — (*Ichthyornis*).

CHARACTERISTICS: Fossil, toothed birds from America, whose teeth are set in sockets.

Order 3 — *Struthioniformes* — Ostriches (*Struthio*).

CHARACTERISTICS: Naked head, neck, and legs; flightless, terrestrial forms; feet with two toes; no keel on breastbone (*sternum*).

Order 4 — *Rheiformes* — Rheas (*Rhea*).

CHARACTERISTICS: Distinguished from preceding order by a partially feathered head and neck; flightless terrestrial birds, with three-toed feet; feathers without aftershaft.

Order 5 — *Casuariiformes* — Cassowaries and emus (*Dromalus*).

CHARACTERISTICS: Terrestrial, flightless birds, possessing small wings; feathers with large aftershaft.

Order 6 — *Crypturiformes* — Tinamous (*Rhynchotus*).

CHARACTERISTICS: Flying, terrestrial birds, with a short tail; no pygostyle.

Order 7 — *Dinornithiformes* — Moas (*Palapteryx*).

CHARACTERISTICS: Recently extinct, flightless, terrestrial birds, with large hind limbs; wing bones absent.

Order 8 — *Aepyornithiformes* — Elephant birds (*Aepyornis*).

CHARACTERISTICS: Extinct terrestrial flightless birds with large hind limbs; small sternum and wings; large eggs.

Order 9 — *Apterygiformes* — Kiwis (*Apteryx*).

CHARACTERISTICS: Small flightless terrestrial birds; hairlike feathers without aftershaft.

Order 10 — *Sphenisciformes* — Penguins (*Eudyptes*).

CHARACTERISTICS: Marine antarctic birds, incapable of flight, with small seal-like feathers; wings modified as paddles for swimming.

Order 11 — *Colymbiformes* — Loons and grebes (*Gavia*, *Podiceps*).

CHARACTERISTICS: Aquatic birds with feet far back with webbed or lobed toes.

Order 12 — *Procellariiformes* — Albatrosses and petrels (*Diomedea*, *Hydrobates*).

CHARACTERISTICS: Marine birds with great powers of flight; webbed toes; bill sheath of several pieces.

Order 13 — *Ciconiiformes* — Storks, birds, pelicans, cormorants, snake-birds, herons, ibises, and flamingos (*Phalacrocorax*, *Ardea*, *Phoenicopterus*).

CHARACTERISTICS: Long-legged aquatic marsh birds with feet adapted for wading.

Order 14 — Anseriformes — Swans, geese, and ducks (*Mergus, Anas, Cygnus*).

CHARACTERISTICS: Aquatic birds whose beak is covered by soft sensitive membrane edged with horny lamellae.

Order 15 — Falconiformes — Falcons, vultures, eagles, hawks, and secretary-birds (*Cathartes, Gymnogyps, Sagittarius, Falco*).

CHARACTERISTICS: Carnivorous birds with curved, hooked beak; feet adapted for perching and provided with sharp, strong claws.

Order 16 — Galliformes — Turkeys, fowls, quails, and pheasants; also the hoactzin (*Meleagris, Colinus, Bonasa*).

CHARACTERISTICS: Arboreal or terrestrial birds; feet adapted for perching.

Order 17 — Gruiformes — Rails and cranes (*Rallus, Gallinula, Fulica*).

CHARACTERISTICS: Mostly marsh birds.

Order 18 — Charadriiformes — Plovers, snipes, gulls, terns, auks, and pigeons (*Jacana, Larus, Rhynchops*).

CHARACTERISTICS: Marine, arboreal, or terrestrial forms.

Order 19 — Cuculiformes — Cuckoos and parrots (*Conuropsis, Coccyzus*).

CHARACTERISTICS: Arboreal birds, first and fourth toes directed backwards; the latter may be reversible.

Order 20 — Coraciiformes — Kingfishers, owls, hummingbirds, swifts, and woodpeckers (*Streptoceryle, Antrostomus*).

CHARACTERISTICS: Tree-inhabiting forms with short legs.

Order 21 — Passeriformes — Perching birds (*Passer, Sayornis, Tyrannus*).

CHARACTERISTICS: More than half of all known birds belong in this order.

In America representatives of 25 families are found. A few of these are the flycatchers, larks, thrushes, thrashers, wrens, warblers, swallows, shrikes, nuthatches, crows, orioles, finches, and creepers.

CLASS IV — MAMMALIA — Mammals.

CHARACTERISTICS: Members of this class are readily distinguished by a covering of hair at some time in their existence; the female possesses mammary glands which secrete milk for nourishment of young.

SUBCLASS A — PROTOTHERIA — Monotremes (*Echidna* and *Ornithorhynchus*).

CHARACTERISTICS: Egg-laying mammals; in case of *Echidna* the egg is placed in a temporary pouch and incubated until hatched.

SUBCLASS B — METATHERIA — Marsupials (*Didelphys*, *Petrogale*, *Macropus*).

CHARACTERISTICS: Carry young in marsupium or pouch; allantoic placenta typically absent.

SUBCLASS C — EUTHERIA — Viviparous mammals.

CHARACTERISTICS: Bring forth their young alive; young never carried in pouch; nourished before birth by placenta.

SECTION A — UNGULATA — Clawed mammals.

Order 1 — *Insectivora* — Insect-eaters, **moles**, and European hedgehogs.

CHARACTERISTICS: Small terrestrial clawed mammals with typically plantigrade feet; molar teeth enameled, rooted, and tuberculate.

Order 2 — *Dermaptera* — **Flying lemurs**.

CHARACTERISTICS: Members of this group resemble the insectivores in the structure of the skull and the canine teeth; only two genera are known, which inhabit the forests of Malaysia and the Philippines.

Order 3 — *Chiroptera* — Insectivorous **bats**, fruit-bats, and blood-sucking vampires.

CHARACTERISTICS: Mammals with claws whose fore limbs are modified for flight.

Order 4 — *Carnivora* — Flesh-eating mammals, hyenas, **raccoons**, dogs, cats, weasels, bears, sea-lions, seals, and walruses.

CHARACTERISTICS: Carnivorous mammals with claws and large projecting canine teeth; incisors small; premolars adapted for flesh-cutting.

Order 5 — *Rodentia* — Gnawing animals, hares, rats, mice, squirrels, beavers, **porcupines**, guinea pigs.

CHARACTERISTICS: Members of this group are usually separated into two suborders depending upon the possession of one or two pairs of incisors in upper jaw.

Order 6 — *Edentata* — So-called toothless mammals, three-toed sloth, **armadillo**, and pangolin.

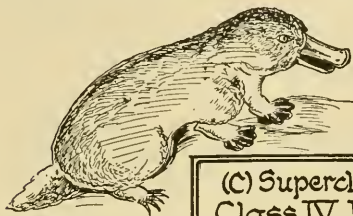
CHARACTERISTICS: Clawed mammals; teeth entirely absent or missing from anterior part of jaw; teeth usually without enamel; tongue often long and protractile.

SECTION B — PRIMATES.

Order 7 — *Primates* — Mammals with nails; **tarsiers**, **lemurs**, **monkeys**, **apes**, **man**.

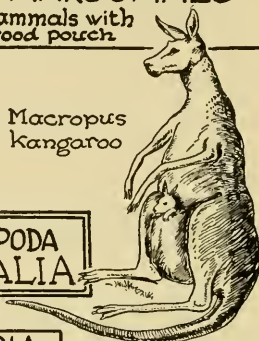
CHARACTERISTICS: Toe or thumb usually is opposable to other digits; dentition rather primitive; eye orbits directed forward; posture usually semierect.

Subclass A PROTOTHERIA
MONOTREMES
 egg-laying mammals



Ornithorhynchus
 duckbill

Subclass B METATHERIA
MARSUPIALS
 mammals with
 brood pouch



Macropus
 kangaroo

(C) Superclass TETRAPODA
Class IV MAMMALIA

Section a
UNGUICULATA
 clawed mammals



Order 1. moles, etc
 Insectivora



Order 2.
 Dermoptera
 flying lemurs



Order 3. bats
 Chiroptera

Order 7
 Primates



Tarsier

Section b
Primates
 mammals
 with nails



Lemurs

Apes

Man



Monkeys

Subclass C EUTHERIA
 viviparous mammals

Order 4 flesh
 eaters
 Carnivora



Order 5
 Rodentia
 gnawing mammals



Order 6
 Edentata
 toothless
 mammals



Order 8
 Artiodactyla
 even-toed



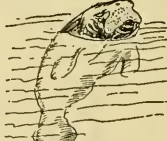
Order 10
 Proboscidea
 trunk and tusks



Section c
UNGULATA
 hoofed mammals



Order 9
 Perissodactyla
 odd-toed



Order 11 sea cows
 Sirenia



Order 12. coneys
 Hyracoidea



Order 13
 Odontoceti
 toothed
 whales



Order 14
 Mysticoceti
 whalebone whales

Section d
CETACEA
 aquatic
 mammals

SECTION C — UNGULATA — Hoofed mammals.

Order 8 — Artiodactyla — Even-toed ungulates; hippopotamus, camel, deer, moose, domestic cattle, **giraffe**.

CHARACTERISTICS: An even number of digits, axis of symmetry passing between digits three and four.

Order 9 — Perissodactyla — Odd-toed ungulates, horse, zebra, tapir, **rhinoceros**.

CHARACTERISTICS: An uneven number of digits, axis of symmetry passing through digit three

Order 10 — Proboscidea — **Elephants**.

CHARACTERISTICS: Ungulates characterized by long, prehensile proboscis; incisors developed to form tusks; broad molars.

Order 11 — Sirenia — **Sea-cows**, dugong, manatee.

CHARACTERISTICS: Aquatic ungulate-type Eutheria; fore limbs finlike; hind limbs absent; tail with horizontal fin.

Order 12 — Hyracoidea — *Hyrax* and **coneys**.

CHARACTERISTICS: Small rodent-like mammals with reduced tail and short ears; four digits on fore limbs; three digits on hind limbs.

SECTION D — CETACEA — Whales and dolphins.

CHARACTERISTICS: Aquatic mammals; probably derived from the Ungulata or Ungulata.

Order 13 — Odontoceti — **Toothed whales**, dolphin, porpoise, grampus.

CHARACTERISTICS: Cetacea with teeth (at least on lower jaw); no whalebone.

Order 14 — Mysticoceti — **Whalebone whales**, fin whale, right whale.

CHARACTERISTICS: Cetacea without teeth in adult; mouth provided with plates of whalebone.

GLOSSARY OF TERMS OCCURRING IN ROLL CALL

- Abdomen** — the posterior region of the body, behind the thorax of an insect; the region of the body below the chest in man.
- Aestivating** — passing the summer in a torpor.
- Aftershaft** — an accessory plume arising from the posterior side of the shaft of the feathers of many birds.
- Alimentary canal** — food tube of animal, beginning with mouth and ending with anus.
- Allantoic** — pertaining to a respiratory sac which in early fetal life grows out from the hind-gut of an embryo.
- Ambulacral groove** — groove in which tube-feet are located.
- Antennae** — paired appendages, which are sensory in function, on the head of an insect or crustacean.
- Antheridium** — organ or receptacle in which male sex cells of ferns are produced.
- Anus** — posterior opening of alimentary canal.
- Appendage** — an organ or part attached to a body, as a leg, arm, fin, or tail.
- Arboreal** — pertaining to forms frequenting trees.
- Archegonium** — a female organ in which the young plant begins development.
- Aristotle's lantern** — masticating apparatus of sea-urchin.
- Ascomycetes** — sac fungi.
- Ascospore** — one of a set of spores contained in a special sac or ascus.
- Ascus** — a membranous spore sac of fungi.
- Asexual** — having no sex.
- Axial** — pertaining to the fundamental central line of a structure.
- Basidiospore** — a spore formed on a basidium.
- Basidium** — the spore-producing organ of certain of the higher fungi.
- Bilaterally symmetrical** — having two symmetrical sides about an axis.
- Bill sheath** — protective covering for bill.
- Bivalve** — consisting of two shells or valves.
- Body cavity** — space in which the viscera lie.
- Branchiae** — gills.
- Calcareous** — containing lime or calcium, chalky.
- Canine tooth** — a pointed tooth situated between an incisor and a bicuspid or premolar tooth.
- Carapace** — a bony or chitinous case covering an animal's back, as in the crayfish.
- Carotin** — yellow pigment of plants; associated with chlorophyll and xanthophyll.
- Carpel** — a pistil, or one of the members composing a compound pistil or seed-vessel.
- Cartilaginous** — gristly substance forming part of the skeleton.
- Caudal** — of, or pertaining to, the tail.
- Cerci** — bristlelike structures.
- Chitin** — a carbohydrate derivative forming the skeletal substance in arthropods.
- Chlorophyll** — green coloring matter found in plants and some animals.
- Chloroplasts** — small bodies of protoplasm containing chlorophyll.
- Chromosome** — a deeply staining body in the nucleus of a cell, supposed to carry the determiners of hereditary characters.
- Cirri** — slender extensions found on bodies and appendages of many forms, which are used for various functions.

- Clasping organ** — specialized holdfast structure of certain males used in copulation.
- Coelenteron** — internal cavity of a coelenterate, which serves as a digestive tract as well as body cavity.
- Coelom** — body cavity.
- Columella** — rodlike bone of middle ear of anura formed from hyomandibular bone.
- Compound eye** — made up of several simple eyes.
- Cotyledon** — embryonic leaf, in a seed.
- Ctenoid scales** — scales with a comblike or serrate margin.
- Cuticle** — an outer layer of the skin.
- Cycloid scales** — scales with evenly curved free border.
- Cytoplasm** — the living substance of the cell outside of the nucleus and inside the cell membrane.
- Deciduous** — falling off at maturity.
- Dentition** — number, arrangement, and kind of teeth.
- Diaphragm** — (*Bot.*) a septum or membranous layer.
- Dicotyledon** — a plant that bears seeds having two cotyledons.
- Digits** — terminal divisions of limb in any vertebrate above fishes.
- Diploblastic** — having two distinct germ layers.
- Direct development** — no metamorphosis, *i.e.*, the young when hatched closely resemble adult except for size.
- Dorsal** — pertaining to the back or top side of (as of a leaf).
- Dorsoventral** — pertaining to structures which extend from dorsal to ventral side.
- Ectoderm** — the outer embryonic layer in a multicellular animal.
- Ectoparasite** — a parasite that lives on the exterior of an organism.
- Elytra** — the anterior wings of beetles, hard and case-like.
- Embryo sac** — the megaspore in plants.
- Endoparasite** — a parasite which lives within the body of its host.
- Endostyle** — ciliated groove whose cells secrete mucus. Found in urochordates and cephalochordates.
- Epithelium** — cellular tissue covering a free surface or lining a tube or cavity.
- Excretory** — pertaining to organs of elimination.
- Exo-skeleton** — an outside skeleton such as the shell of a lobster.
- Fibrovascular bundles** — collections of tubular cells, supported by woody cells, which conduct fluids in plants.
- Filamentous** — composed of long, threadlike structures.
- Flagella** — threadlike projections of cells, which are used for locomotion.
- Flame cell** — the terminal cells of branches of excretory system in flatworms, with cavity continuous with lumen of duct, and containing a cilium or bunch of cilia, the motions of which give a flickering appearance similar to that of a flame.
- Foot** — thick muscular locomotor organ of molluscs.
- Furcula** — a forked process or structure.
- Gamete** — a mature sex cell.
- Gametophyte** — a stage in the life history of a moss or fern in which sex cells are produced.
- Ganglion** — a group of nerve cells situated outside of the brain or spinal column.
- Gastric** — pertaining to or in region of stomach.

- Gastrovascular** — serving both digestive and circulatory purposes.
- Germ cell** — sex cell.
- Gill cleft** — a branchial opening formed on the side of the pharynx.
- Gill filaments** — the soft filamentous structures on the respiratory organs (gills) of aquatic animals.
- Gland** — an organ which secretes material to be used in, or excreted from, the body.
- Halteres** — a pair of small capitate bodies representing rudimentary wings in flies, used as balancers.
- Haploid** — having the number of chromosomes characteristic of mature germ-cells for the organism in question.
- Hemocoel** — an expanded portion of the blood system which takes the place of a true coelom.
- Hepatic caecum** — blind pouch or diverticulum of or in region of liver.
- Hermaphroditic** — pertaining to an organism with both male and female reproductive organs.
- Heterocercal** — having vertebral column terminating in upper lobe of fin, which is usually larger than the lower.
- Homocercal** — with equal or nearly equal lobes, and axis ending near middle of base.
- Hypa** — one of the filaments composing the mycelium of a fungus.
- Incisors** — front chisel-like teeth of either jaw.
- Incubate** — to keep warm and under other favorable conditions for hatching.
- Indirect development** — undergoing metamorphosis, *i.e.*, showing a decided change in form and appearance from time of hatching until maturity.
- Integument** — a covering or protective layer; skin.
- Keel** — ridgelike process.
- Lamellae** — thin platelike structures.
- Larvae** — young stages in the development of some forms of animals, which become self-sustaining but which do not have the characteristics marking adults.
- Lateral line** — longitudinal line at each side of body of certain aquatic animals marking position of sensory cells.
- Laterally compressed** — narrow from side to side.
- Ligament** — a band of connective tissue binding one bone to another.
- Lobate** — divided into lobes.
- Lophophore** — ridge bearing tentacles.
- Lung-books** — respiratory organs formed like a purse with numerous compartments or a book with edges of leaves exposed.
- Mammary glands** — milk-secreting glands.
- Mantle** — the soft outer fold of skin in molluscs which secretes the outer shell.
- Medusoid** — like a jellyfish or medusa.
- Megasporangium** — a macrospore-producing sporangium in plants.
- Megaspore** — larger spore of heterosporous plants, regarded as female; embryo-sac cell of seed plant.
- Membranous** — resembling or consisting of a membrane; pliable and semi-transparent.
- Mesenchymatous** — pertaining to mass of tissue intermediate between ectoderm and endoderm, derived from mesoderm.
- Mesenteries** — peritoneal folds serving as a bridge for blood vessels and for holding organs to body wall.
- Mesoderm** — the middle layer of tissue in a young animal embryo.

- Mesoglea** — an intermediate non-cellular layer in sponges and coelenterates.
- Metamorphosis** — change in form or structure of an animal in its development from embryo to adult.
- Gradual or simple metamorphosis — young resemble adults at hatching except for absence of wings or color, shape, and structure of some appendages.
- Complete metamorphosis — young differ from adults in appearance, habitat, etc., and undergo several changes in form such as larvae, pupae, and adult.
- Metathorax** — posterior segment of insect's thorax.
- Molars** — grinding teeth.
- Monocotyledon** — a plant that bears seeds having but one cotyledon.
- Mother cell** — primary cell before division occurs.
- Mycelium** — the threadlike body of a mold, or other fungus; made up of individual threads called hyphae.
- Nematocyst** — a stinging cell.
- Nervure** — one of riblike structures which support membranous wing of insect.
- Notochord** — a rod of cells forming the supporting axis of lower chordates; found in early stages of development in all vertebrates.
- Nucleus** — the center of activity in the living cell.
- Nymph** — larva of aquatic forms which undergo gradual or simple metamorphosis.
- Oögonia** — female reproductive organs in certain Thallophytes; the mother egg cells.
- Operculum** — a lid or cover.
- Oral** — pertaining to the mouth; side on which mouth lies.
- Ovary** — (*Bot.*) the base of a pistil, containing the ovules.
(*Zool.*) — the egg-containing organ.
- Ovule** — egglike cell of a plant.
- Papillae** — any small nipplelike projections or parts.
- Parapodia** — paired appendages used in locomotion, attached to body segments of some marine worms.
- Parasites** — animals or plants which live at the expense of other organisms.
- Parietal eye** — rudimentary eye arising as an evagination on the median dorsal surface of the brain.
- Parthenogenesis** — reproduction without fertilization by a male element.
- Pedicellariae** — minute pincerlike structures studding the surface of some of the echinoderms.
- Pentamerous** — made up of five parts.
- Peritoneum** — membrane which lines the abdominal walls and invests the contained viscera.
- Phylogenesis** — history of evolution of species.
- Placenta** — organ through which the mammalian embryo is nourished by the mother.
- Placoid scales** — embedded scales and dermal teeth of elasmobranchs.
- Plantigrade** — walking with sole of foot touching the ground.
- Plasmodium** — a single mass of living material which contains many nuclei.
- Plastid** — small bodies of specialized protoplasm lying in cytoplasm of some cells — especially plants and certain protozoans.
- Plastron** — ventral bony shield of tortoises and turtles.
- Poison gland** — gland which secretes poison, used for protection or food-getting.
- Pollen tube** — a tubular process developed from pollen grains after attachment to stigma.

- Polyp** — a separate zooid of a colonial animal.
- Prehensile** — adapted for holding.
- Premolars** — bicuspid teeth between canine and molar teeth.
- Proboscis** — any of various tubular prolongations of the head of animals; muscular protrusible part of the alimentary canal in certain worms.
- Procoelus** — with concave anterior face.
- Prothallus** — a small, thin, gametophytic mass of tissue developed from spores of ferns.
- Prothorax** — anterior thoracic segment of arthropods.
- Protractile** — capable of being thrust out.
- Pseudopodia** — protrusions of protoplasm (false feet) serving for locomotion and prehension in protozoa.
- Pygostyle** — an upturned compressed bone at end of vertebral column of birds, formed by fusion of caudal vertebrae.
- Pyloric caecum** — a blind diverticulum or pouch in the pyloric region.
- Pylorus** — the aperture between the stomach and the small intestine.
- Pyrenoid** — a colorless plastid of lower plants, a center of starch formation.
- Quadrato bone** — the bone with which the lower jaw articulates with the cranium in some forms.
- Radially symmetrical** — having similar parts arranged on either side of a central axis.
- Reproduction** — the process by which organisms produce offspring. In *asexual* reproduction a new organism is formed by the separation of a cell or cells from a single parent; in *sexual* reproduction two cells from two plants or two animals of different sexes join together to form a new individual.
- Rhizoids** — rootlike organs.
- Rhomboidal** — shaped more or less like an equilateral parallelogram, having its angles oblique.
- Rodent** — animal with a habit of gnawing or nibbling.
- Sap cavity** — a vacuole, filled with water and dissolved substances in mature, live plant cells.
- Saprophytes** — organisms which live on dead and decaying organic matter.
- Scale** — a flat, small, platelike external structure, dermal or epidermal.
- Schizogony** — repeated division of the nucleus without immediate cell division.
- Sedentary** — not free-living; animals attached by a base to some substratum.
- Segmentation** — the division or splitting into segments or portions; cleavage of an ovum.
- Sessile** — stationary or attached, opposite of free-living or motile.
- Setae** — bristlelike structures.
- Siphon** — a tube through which water may pass into and out from the mantle cavity of a mollusc.
- Sperm** — male sex-cell.
- Spicules** — siliceous or calcareous secreted skeletal structures of sponges.
- Spiral valve** — a spiral infolding of intestinal wall.
- Spongin** — material of skeletal fibers of certain sponges.
- Sporangium** — a sac containing spores.
- Spore** — a type of reproductive cell, usually asexual, with a protective covering enabling it to survive unfavorable environmental conditions.
- Sporophyll** — a sporangium-bearing leaf of ferns.
- Sporophyte** — spore-bearing stage in the life cycle of a plant.
- Stapes** — stirrup-shaped innermost bone of middle ear of mammals.

- Sterigma** — a slender filament arising from basidium, giving rise to spores by abstriction.
- Stigma** — the part of a pistil which receives the pollen grains.
- Tarsal** — pertaining to the tarsus or last region of the leg of an insect; the ankle bones of vertebrates.
- Tentacles** — flexible organs at the oral region of an animal, used for feeling, grasping, etc.
- Thallus** — a simple plant body not differentiated into root, stem, and leaf.
- Thorax** — the part of the body between the head and abdomen.
- Tracheae** — respiratory tubes of insects.
- Tracheal gills** — small winglike respiratory outgrowths from the abdomen of aquatic larvae of insects.
- Triploblastic** — with three primary germinal layers.
- Trochophore** — free-living pelagic, ciliated larval stage.
- Tube-feet** — organs of locomotion of echinoderms.
- Tuberculate** — resembling or having root-swellings or nodules.
- Ungulates** — hoofed animals.
- Vascular** — consisting of or containing vessels adapted for transmission or circulation of fluid.
- Vein** — branched vessel which carries blood to heart; rib or nervure of insect wing.
- Velum** — a membranous partition likened to a veil or curtain.
- Ventral** — pertaining to the belly surface or under side.
- Vertebrae** — bones of the vertebral column (backbone).
- Vestigial** — small and imperfectly developed; rudimentary.
- Whorl** — (*Bot.*) circle of flowers or parts of a flower arising from one point. (*Zool.*) spiral turn of univalve shell.
- Xanthophyll** — a yellow pigment invariably associated with chlorophyll in higher plants.
- Zoospore** — a motile spore of either plants or animals.

FUNDAMENTALS OF STRUCTURE AND FUNCTION

V

LIFE AND PROTOPLASM

PREVIEW. What is being alive? · Metabolism · Some signs of manifestation of life · The production and use of enzymes associated with living things · Structure of protoplasm · Protoplasm and the cell · Chemical organization of living matter · Protoplasm a complex mixture · Protoplasm a colloidal mixture · Diffusion · Osmosis and its significance to living cells · Suggested readings.

PREVIEW

Being alive is something that we all know a little about. Liveliness is associated with those of one group who are "up and coming," those who are active, both mentally and physically. If living things are thought about a little more closely, certain things are attributed to them: they move, feed, grow, are sensitive, and they reproduce their kind. The scientist goes a step further and compares the living things with those which do not possess this mysterious something we call life. He says life is a manifestation of forces, like a flame, or electricity. He goes beyond superficial observation and asks himself a good many questions about the make-up and action of the living things which fill his environment. Some of the problems with which one is confronted are relatively simple and may be solved with a little close observation, even without the aid of a microscope, but other problems are speculative and may never be answered in full.

If the problems were to be assembled with a view to attempting their solution, some of the more important might be the following: What is being alive? What differentiates living stuff from non-living? What is known about the ultimate composition of the living stuff? Is it different for animals and for plants? And what common characteristics can be found for plants and animals?

It is obvious that our problems resolve themselves into two groups, those which are more or less speculative and those which depend on the knowledge provided by the physicist, chemist, and biologist. The newer knowledge of chemistry and physics and the use of the refinements of the compound microscope have made possible much that was undreamed of a few decades ago. It is only 260 years since

the first simple microscopes of the Dutchman, Antony van Leeuwenhoek, but enormous advances have been made in this period. The most rapid advances in chemistry, physics, and biology have come in the last two or three decades, but we are still far from the solution of the great riddle of the universe — What is life, and from whence did it come?

What Is Being Alive?

The chemist or the biologist weighs the food an organism eats and thus finds out that much of the energy locked up in food is transformed within the body of the organism, ultimately to be released in another form, either in heat production or in work of some kind. Not only do living things release energy but they also grow and are able to repair parts that are wasted or lost. Think of the athlete, hale and hearty, winning points for his team; losing weight in a football game, making it up after the game at the training table, or imagine the same athlete recovering from a severe illness, or with his leg in a cast after an accident. One may feel fairly sure that he will soon be well again. The living stuff of which he is made will not only use the food to release energy for his normal processes, but will also rebuild the expended body material and rid itself of such wastes as result from the process. Put in another way, this living stuff of which an athlete is composed has the ability to take in food, to use this food for the release of the energy stored up in it, or, under certain conditions, to make some of the food over into living material. Living things thus have the capacity for growth, for waste and repair, and, like man-made machines, have the ability to use food fuel, and to release energy from it.

Metabolism

The sum total of all the processes involved in the business of being alive is called *metabolism*. This series of processes is twofold: first, constructive metabolism, or *anabolism*, in which the food material becomes a part of the living organism, the energy being held there in a potential form; and second, by destructive metabolism or *katabolism*, in which the body material is broken down to release energy, and in which, as a result, there is the production of work and a passing off of waste products. This text is concerned, by and large, with the various phases of metabolism which will be considered in greater detail later.

Some Signs of Manifestation of Life

One sign of life is the release of energy, which is a result of respiration. It occurs in all living things, be it a tree, a frog, or a man, when oxygen is taken into the body, where it combines with oxidizable materials to release energy. The by-products are carbon dioxide and water, which are given off by the organism.

Living things are sensitive to and respond to various stimuli in their environment. The plant in the window, the earthworm in the ground, the fish in the water, and the bird in the tree are all sensitive to and respond in different ways to the stimulus of light. Temperature, chemical substances, gravity, electricity, radiations, and mechanical factors, all are stimuli which affect living things in different ways. It is this characteristic of living things that we call *irritability* or *sensitivity*.

One direct outcome of the ability of living things to respond to stimuli in their environment is their *adaptiveness*. Thus living organisms have the capacity to adjust themselves to changes in conditions. Some plants throw out new roots, or suckers, or trailing stems, by means of which they can get a foothold in slightly different environments from those in which they are accustomed to live. Certain low forms of plants have even become adapted to live in the hot springs as those in the Yellowstone National Park, in a habitat many degrees warmer than that of their near relatives found in adjoining pools. Fishes, and certain small crustaceans, may similarly adapt themselves to life in water containing a high concentration of salts. This power of adaptation is a quality of the organism as a whole, and results in adjustment between the external environment and the internal body material.

The Production and Use of Enzymes by Living Things

In recent years a good deal of work has been done by physiologists to see how the cell is able to perform the cycle, in which material is taken into the organism as food or is made into food as in the case of green plants. Food is changed into a soluble form so that it may pass through the delicate living membrane of every cell. Meantime each cell is using oxygen, which also has to be taken in through the cell membrane, while wastes are given off by the same road. Physiologists seem agreed that these living processes, called digestion, absorption, respiration, and excretion, are made possible by the

presence of substances called *enzymes*, which act as catalyzing agents, thus hastening by their presence the performance of such functions. (See pages 279–280.) Enzymes are manufactured in certain cells and it is believed that every cell, even an egg cell, contains enzymes which are capable of digesting food substances, as well as those which aid in oxidation within the cell.

In plants, enzymes seem to be made in almost any cell that is active and these enzymes usually have a reversible action. For example, certain insoluble foods may be broken down or hydrolyzed in the cells of the leaf, so that they are soluble, then they will pass in that condition to the stem, the roots, or the fruit, where a reverse action takes place and the food is stored in an insoluble condition. In animals, the hydrolyzing enzymes which make digestion possible are usually formed by groups of cells forming glands.

Structure of Protoplasm

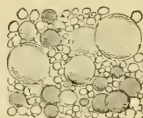
This living material, known as *protoplasm*, has been called by the biologist Huxley “the physical basis of life.” It is this stuff that is



granular
structure
1



reticular
structure
2



alveolar
structure
3

Three states of protoplasm. 2 and 3 have much higher magnification than 1.

always present in things that are alive. In our present state of knowledge we may liken it to the albumen or white of egg, a nearly colorless and translucent substance, like soft jelly.

This substance seen under the compound microscope has many granules floating in it. It is more or less elastic, although in some cases it will flow like a dense liquid. Seen under a high magnification it may be almost homogeneous in structure or may appear foamy or spongelike, or even fibrillar in appearance. A study of living cells shows that it is obviously quite different in structure at different times and in different animals and plants.

Protoplasm and the Cell

Although cells were first described in 1665 by Robert Hooke, it was not until the nineteenth century that the cell theory came into the spotlight. The knowledge that all organisms, plant and animal, are composed of fundamentally identical protoplasmic units, or cells,

forms one of the most important corner stones in the foundation of biology.

While plant and animal cells possess some rather striking differences in organization, they are fundamentally similar. Practically every cell that is microscopically visible possesses several different kinds of structures located within its borders. Some of these structures are alive, some lifeless. In the first group may be placed the *plastids* of plant cells, the *mitochondria* or *chondriosomes*, some of which probably give rise to plastids, fibers of various kinds, the *Golgi bodies* and the *centrosomes*, the latter of importance in animal cell division. In the second group may be placed such inclusions as yolk, or other food substances, *fatty droplets*, *granules* of pigment or of *secretions* (as in gland cells), and *crystals* of various kinds, such as calcium oxalate in plant cells. To this list may also be added *vacuoles*, which in plant cells often occupy the major space within the cell membrane. All of these structures are confined to the *cytoplasm* or part of the protoplasm outside the nucleus. In *Elodea*, the cells present a green appearance, due to the presence of many tiny ovoid bodies, the *chloroplasts*, which are plastids containing *chlorophyll*. Careful observation of a single cell shows that the chloroplasts move slowly down one side of the cell, across one end, and up the other side, keeping rather close to the outer edge of the cell during the process. This is due to the movement of the cytoplasm. In the cells of the hairlike stamen of *Tradescantia*, the movement of the cytoplasm is also evident. Here it can be seen actively streaming in currents within the cell, carrying along within it tiny crystals of inorganic origin, as well as colorless plastids and granules. The latter term is usually applied to inert materials, such as granules of *stored food* in the form of starch grains (in plants), fat or yolk granules, or *pigment granules* which frequently occur scattered throughout protoplasm. Between the strands of cytoplasm are spaces or *vacuoles* filled with a watery fluid, called *cell sap*. In young plant cells, the vacuoles are small and the cytoplasm occupies the greater part of the cell, but in mature plant cells the cytoplasm is found close

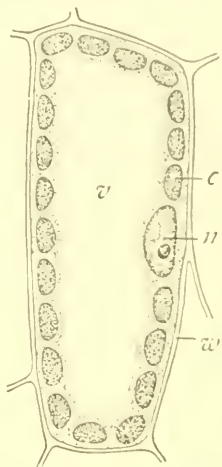


Diagram of a mesophyll cell of a leaf:
c, chloroplast; n, nucleus; v, vacuole;
w, cell wall.

to the outer part of the cell, while the vacuoles form large sap cavities within the cell. Although *Golgi bodies* appear much less stable and more changeable in form than plastids, they are found in many kinds of plant and animal cells. *Fibrils* of various kinds, such as those

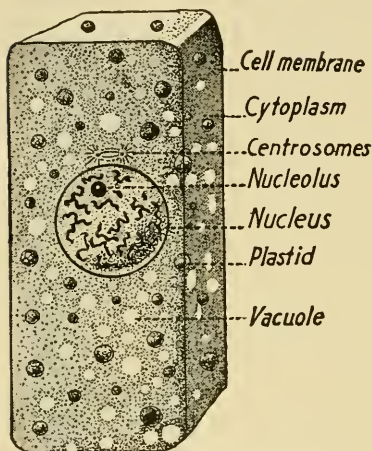


Diagram of a typical animal cell.

seen in a muscle cell, are frequently found. In plants the cell wall, a delicate but rigid, secreted cellulose covering, is lined with a delicate living membrane which separates the living stuff from the cell wall. At one point can be found a slightly denser jellylike part of the protoplasm called the *nucleus*. Both the vacuoles and the nucleus are separated from the cytoplasm by delicate membranes. In many but not all nuclei, dense, dark-staining *nucleoli* appear. While their function is not clearly understood, they generally break up and disappear

during cell division. The nucleus proper is a vital, definite part of every living cell and is of great importance in cell division which must take place if a many-celled organism is to grow in size, for growth takes place by an increase in the *number* of cells, not in the *size* of the cells. The nucleus is filled with *nuclear sap*, in which is found a network of *linin* fibers. On these fibers are scattered numerous granules of *chromatin*. This material, which as we will see later forms *chromosomes*, is of the greatest importance, as through it plants and animals are able to pass on to successive generations their inheritable qualities.

Chemical Organization of Living Matter

A dozen or more of the ninety-odd elements recognized by the chemist are found in living protoplasm, — carbon, hydrogen, oxygen, and nitrogen comprising the greatest bulk. These elements also form the basis of our so-called organic foodstuffs, which are called *proteins*, *carbohydrates*, and *fats*. The two latter groups of substances are made up of carbon, hydrogen, and oxygen, while the proteins have the element nitrogen added to their constitution, along with sulphur, phosphorus and sometimes iron. In a simple carbo-

hydrate, such as glucose, for example, the chemist writes a formula representing a molecule of the substance. In such a simple molecule the atoms of hydrogen and oxygen are usually united in the same proportion as in water and the empirical formula is written $C_6H_{12}O_6$. This water proportion (H_2O) is maintained in other more complex carbohydrates such as starch, but here the chemist writes an x after the empirical formula $(C_6H_{10}O_5)x$. This means that the molecular formula is not exactly known but in the case of starch the x should probably be about 200, which makes the molecule very much larger than that of the simple sugar. The simple sugars with their small molecules are easily soluble in water, while the complex molecule of the starch is not so soluble. In fatty substances, oxygen is present in a much smaller proportion than in the carbohydrates. An example might be oleic acid, one of the components of butter fat, $(C_{18}H_{34}O_2)$. Proteins have still more complex molecules. In the first place they are built up of simpler substances, called *amino acids*, and in some cases other radicals are added to them. For example, in the cell nuclei the protein is combined with nucleic acid, which has the astonishingly complex formula $C_{35}H_{49}O_{29}N_{15}P_4$, which really means very little except to the student of chemistry.

Protoplasm a Complex Mixture

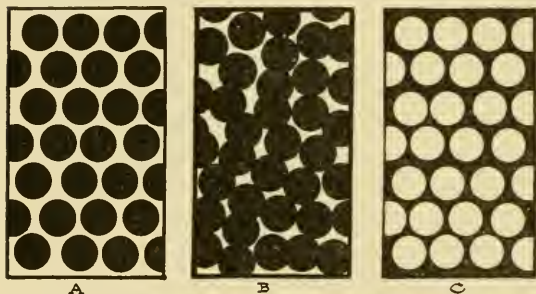
Living stuff, having the same elements as the complex foodstuffs for a basis, is even more intricate. No chemical compounds in nature are quite as complicated in composition, for protoplasm not only is made up of the foodstuffs but it also consists largely of water. One estimate by weight gives 80 per cent water, 15 per cent proteins, 3 per cent fats, 1 per cent carbohydrates and other organic substances, and 1 per cent inorganic salts. It has been determined that carbon, nitrogen, hydrogen, oxygen, and phosphorus are always present in protoplasm and are called the primary elements. Magnesium, potassium, iron, and sulphur appear equally necessary for life. Sodium and chlorine are always found in animal but only infrequently in plant tissues, and calcium appears necessary for life in the higher forms. Other elements, bromine, fluorine, iodine, silicon, boron, manganese, and even copper, zinc, and aluminum, are found in some organisms.

While some of these elements are solids and others gases, none of them, except oxygen, typically occurs to any marked extent free in the organism. Nor are they found free in the foods or waste products, but rather as various kinds of chemical compounds which

may be further subdivided into inorganic and organic compounds. The former comprise most of the non-living compounds such as soil and rocks and their decomposition products. However, in protoplasm, inorganic compounds are usually present as water, salts, or gases. Water is important not only because it comprises 70–98 per cent of protoplasm by weight, but also because it dissolves so many different substances. Furthermore, water is an important factor in promoting the dissociation of many salts into their constituent ions. The inorganic salts which occur in marine organisms, for example, are usually those commonly found in sea water. Some, such as nitrates and nitrites, occur chiefly in plants, while compounds containing sodium and chlorides are characteristic of animal tissues. Only three gases are found in varying amounts in the living cell, — free oxygen, carbon dioxide, and ammonia.

Protoplasm a Colloidal Mixture

Matter exists in three states, gaseous, liquid, and solid. Frequently it passes from one state to another, as when ice melts under the in-



Colloidal constitutions. The continuous phase in a sol (A) being fluid; in a jell (C) solid; while in the intermediate phase (B) the solid forms a net through which the fluid is continuous.

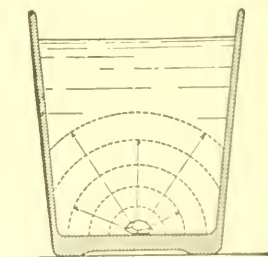
fluence of heat, turning to steam as the water boils away. That protoplasm at different times and under different conditions varies in appearance is probably due to the fact that it is a *colloid* and as such can change from a "sol," or liquid, to a "gel," or solid state and then, under cer-

tain conditions, back again. The scientist examines protoplasm under the ultramicroscope and finds tiny dancing particles which are invisible under the ordinary illumination of the microscopic field (Brownian movement). This condition is known as a *dispersion*, the dispersed particles being carried in the dispersion medium, in this case water. A fog composed of tiny droplets of water is an example of dispersion in nature. If the particles in a dispersion are small, the substance is called a *crystalloid*, when large it

is called a *colloid*. Now these terms are not applied to fixed substances but to states of matter. Gelatin passes from a liquid to a solid state on being heated or cooled. A study of the diagram shows how this might be possible. In the left-hand diagram the solid particles are floating freely in the fluid of the medium; in the middle diagram the solid portion is becoming a loose mesh; while in the right-hand diagram the mesh has become a solid mass, including the liquid within it. The protoplasm within the cells of plants and animals probably behaves in a similar manner, under some conditions assuming the "sol," and at others the "gel" state. Remembering that protoplasm is not a single protein substance, but rather a mixture of proteins, fats, carbohydrates, and sometimes even other substances, it is clear why there are many slightly different protoplasmic depending on the part of the animal or plant examined. This fact may help us to see why the living matter of a muscle, the blood, or the brain differs visibly in structure. For one thing, the water content differs greatly. Living bone is said to be 25 per cent water, muscles about 75 per cent, the jellyfish almost 99 per cent, and some fruits as high as 98 per cent water.

Diffusion

We have spoken of the work of the enzymes in making food substances soluble. Let us now see why solubility is necessary for the life processes of cells. The physical phenomenon of *diffusion* is easily demonstrated by the slow spread of red ink when a drop is put into a glass of water. Brownian movement of dancing particles visible under the high power of the microscope is a manifestation of molecular kinetic energy caused by the water molecules bombarding these particles. It is a similar movement of molecules that occurs when diffusion takes place. Molecules of any substance are always in motion. If this substance is soluble (the *solute*) in another substance (the *solvent*), there is always a tendency for these molecules to move from the place of their greatest concentration to places where they are not so highly concentrated, until an equilibrium is reached and there



Longitudinal section through a tumbler of water containing soluble crystal, showing by arrows the direction of diffusion, and by dotted circles the lines of equal concentration.

are just as many molecules of the solute in one part of the solvent as in another. In the case of the diffusion of red ink in water, the eosin (which is the coloring material used) was more concentrated in the drop than in the water, so the molecules of eosin began moving away from this place of high concentration until they were equally dispersed throughout the water. As a general rule we may say that, if other conditions are equal, the diffusion rate between two points is proportional to the differences in concentration of the substances at these two points. One thing which affects the diffusion rate is the nature of the medium, whether it be a gel, emulsion, or some sort of semisolid (porous). Gelatin, for example, which is a gel, offers no effective resistance to the diffusion of molecules of a crystalloid nature through its meshes, but, upon the other hand, this network may serve to block effectively the passage of colloidal substances.

Suppose a membrane were stretched crosswise in a jar where diffusion was taking place. Could the molecules of the diffusing substance pass through the membrane? This depends on whether the membrane is permeable to the diffusing substance. In some membranes the ultramicroscopic "pores" are believed to be quite large, thus letting through molecules of larger sizes, while in other membranes the "pores" through which substances can diffuse are

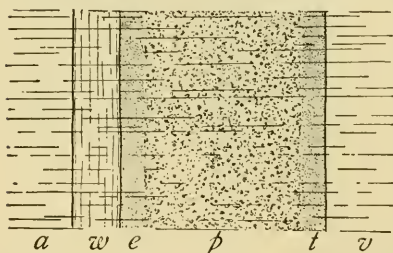


Diagram of an imaginary section through the cell wall and protoplast to show *a*, outer water; *w*, cell wall; *e*, ectoplasm or cytoplasmic membrane next to the cell wall; *p*, general cytoplasm; *t*, tonoplast or inner cytoplasmic membrane next to the water, thus forming a continuous pathway which carries solutes from (*a*) to (*v*); *v*, vacuole.

very small. Other substances penetrate in proportion to their lipid solubility. Thus some membranes allow certain substances to pass through, while they keep out others. Such membranes are said to be *selectively permeable*. An ordinary parchment membrane will allow the eosin to pass through it. But the cell membrane does not act in the same manner, as it is a *plasma membrane*, and selectively permeable.

The plasma membranes surrounding living cells are believed to be colloidal in nature, made of a combination of fatty and protein substances. Careful experiments have demonstrated them to be

selectively permeable. Most living cells allow oxygen and carbon dioxide to pass freely through their membranes, while dissolved sugars and digested proteins in the form of amino acids diffuse through more slowly. Water of course passes through, acting as a vehicle for other substances. Such membranes are impermeable to certain salts and not to others. The permeability of living cells to dissolved substances differs with the cell, and naturally with the organism. Salt- and fresh-water fishes are examples of types, the cells of whose gills exhibit different permeabilities. Dead cell membranes are usually permeable to crystalloid solutes, while living cell membranes permit but few salts to enter. In general, cells are not permeable to colloids, because of the large size of the particles constituting the colloid.

Osmosis and Its Significance to Living Cells

We have already seen that if a membrane is selectively permeable, then some substances, such as water or certain solutes, will pass through readily, but other solutes may not, because their molecules are too large to pound their way through the ultramicroscopic "pores" of the membrane. The process by which substances diffuse through membranes is known as *osmosis*. It is of the greatest importance to living cells, as it is by this means that dissolved gases, such as oxygen, and dissolved food substances get into the cell, as well as the process by which waste materials pass out. Perhaps a further word of explanation is in order.

Other things being equal, if two solutions of different concentrations are separated by a permeable membrane, the diffusion will still be in the direction of the greater to the lesser concentration. Thus if a sugar solution be separated by a permeable membrane from another more dilute sugar solution, diffusion will take place from the more concentrated. If, however, we separate water from a

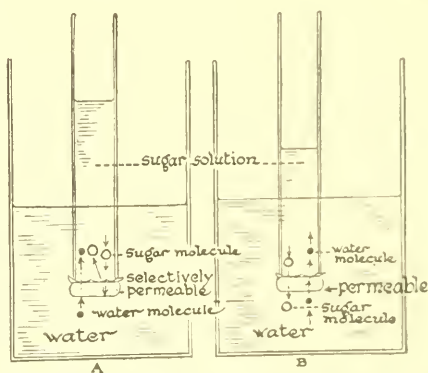
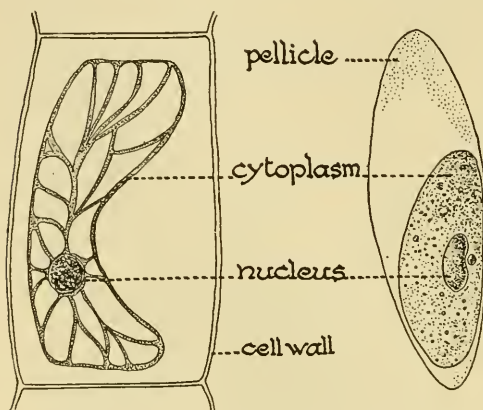


Diagram to explain osmotic pressure. Sugar solution is of equal density in each tube. Explain rise of solution in left hand tube.

sugar solution by a selectively permeable membrane, the water molecules tend to pass through the membrane (since it is permeable to water) from the water, to the sugar solution where the water is in less concentration. Actually it is a question of the water molecules of the solvent reaching an equilibrium.

Osmotic pressure, in living cells, is one of the factors that accounts for the rise of water in roots and up the stems of plants. Its effects can easily be demonstrated experimentally in the laboratory by placing, for example, living cells of *Spirogyra* in a 10 per cent solution of salt and water. The water from within the cell (where it is in greater concentration) passes out through the cell membrane to enter the salt solution (where water is in less concentration than in the cell). The result is that the cell body shrinks away from the cell wall and the shrunken cell is said to be *plasmolyzed*.



Plasmolysis in a plant and an animal cell. Note how the cytoplasm has shrunk away from the wall in the case of the plant cell and the pellicle in the case of *Paramecium*. Why has this occurred?

A solution which contains a greater number of molecules of the substance in solution (solute) per volume than the interior of the cell is said to be *hyperosmotic*; if it has less concentration than the interior of the cell it is *hyposmotic*; and if it has the same number of solute molecules per unit volume as the interior of the cell the solution is *isosmotic* to the cell.

When a cell is placed in a *hyposmotic* solution it will tend to swell up, because water is diffusing

more rapidly inward, and so, unless the cell is surrounded by heavy walls as in the case of plants, the cell will tend to burst. When this happens it is called *cytolysis*. This may be demonstrated when human red blood corpuscles are placed in distilled water. It is evident, therefore, that osmotic pressure differs greatly in the cells of different organisms, possibly depending on whether they live in fresh or salt water and the consequent concentration of salts present. As a matter of fact, fresh-water organisms live in a

hypotonic solution. In plants, the cell walls prevent the cells from swelling up, while in animals there are special ways of ridding the body cells of excess water.

SUGGESTED READINGS

Calkins, G. N., *Biology of the Protozoa*, Lea and Febiger, 1926. Ch. I.

A full and scientific approach to the cell.

Plunkett, C. R., *Outlines of Modern Biology*, Henry Holt & Co., 1930. Chs. I and IV.

A chemical and physical approach to the study of protoplasm.

Singer, C. J., *The Story of Living Things*, Harper & Bros., 1931. Chs. IV and IX.

An interesting history of biology. Chapters IV and IX deal with the historical approach to the cell theory.

Wilson, E. B., *The Cell in Development and Heredity*, The Macmillan Co., 1925.

A classic authority on the cell.

VI

CELLS AND TISSUES

PREVIEW. Living things composed of cells · Plant and animal cells differ in size, shape, and structure · Why cells divide · How plant cells divide · How animal cells divide · Tissues · The tissues in plants; the meristematic tissues; the protective tissues; the fundamental tissues; the conducting tissues; the tissues in animals; the epithelial tissues; the supporting tissues; the muscular tissues; circulatory tissue; the nervous tissues; reproductive tissues · Why are living organisms so called? · Suggested readings.

PREVIEW

One characteristic of living things is that they are organized into tiny units of living matter which have been called, rather inaptly, "cells," because an Englishman, Robert Hooke, as early as 1665, described the construction of cork which he saw under a lens as "little boxes or *cells* distinguished from one another." He cut cross sections with a penknife and saw that they were "all cellular or porous in the manner of a honeycomb, but not so regular." What Hooke saw was the woody walls enclosing spaces which in younger plants would be filled with living matter.

From a comparison with the simplest organisms, it is evident that the more complex forms are built up of cells, and that, although each cell can function as an organic whole, far more efficient results are obtained when groups of cells organized into *tissues* do the work. The consideration of groups of cells, according to their structure and function, constitutes in itself a major chapter in biological study, called *Histology*. The study of individual cells, which make up the subject matter of *Cytology*, is absolutely indispensable to a proper understanding of the organism as a whole.

The problems for reading and further study are so numerous that we might spend the major part of our available time in discussing them. Why and how do cells divide? What are the differences between plant and animal cells? What are the reasons for having tissues and organs? How did many-celled organisms come into existence, and why? The pages which follow will enable the student to make at least a start on some of these interesting questions.

Living Things Composed of Cells

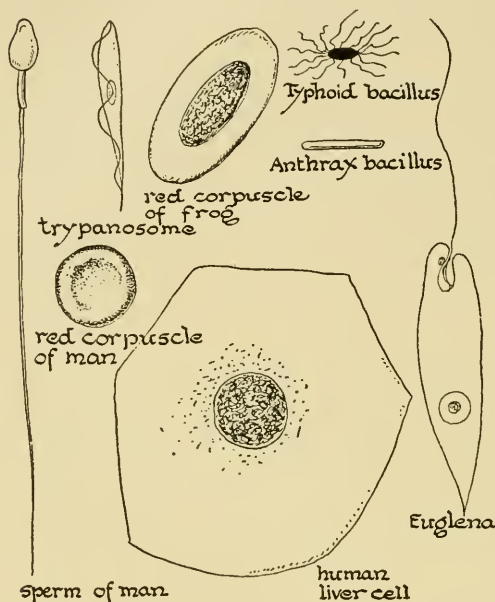
A very small proportion of living plants on the earth are unicellular, but according to Hegner, the number of species of protozoa or single-celled animals must be nearly, if not quite, as great as all the other species of animals put together. He bases his estimate upon the fact that practically every kind of animal has its own species of parasitic protozoa living upon or within it. Nevertheless the *metazoa*, as the many-celled animals are called, make up most of the living animals that we know about on earth today, just as the many-celled plants make up the visible and familiar plant life.

Just how the many-celled forms of life evolved from the unicellular forms is a matter of conjecture. Two theories of origin in animals have arisen, one of which, the *colonial theory*, postulates many-celled organisms evolving as colonies of cells, which hold together after fission to form plants or animals, instead of separating into individual isolated cells. As these cell masses evolved, they became more and more complex, different systems of organs appearing in more highly organized forms. In the animal series shown on page 146, this theory seems to be pretty well substantiated. But another theory, the *organismal theory*, considers the living thing as a whole, being divided into units of structure in the many-celled organism. According to such a theory unicellular organisms would become first much differentiated within their own bodies, as is seen in many of the protozoa. These theories need not concern us further at present. Both have many facts to support them, substantiated by the development and structure of various types of organisms.

Plant and Animal Cells Differ in Size, Shape, and Structure

An examination of the figure on page 140, will show that cells are far from uniform in size and shape. They differ in size from the smallest bacteria which can just be distinguished with an ultra-microscope that magnifies 3000 diameters, to cells that can be seen with the naked eye. The egg-cell of the chick, for example, includes the conspicuous yolk, while certain cells in the human spinal cord, although microscopic in size, may have prolongations reaching down into the muscles of the fingers or toes. Cells are not of necessity larger in large animals or plants, some of our largest cells being found living isolated and alone. But under normal conditions a cell of a given size and shape always reproduces the same kind of cell as itself.

As to shapes, their name is legion. A typical cell might be thought of as a spherical or ovoid body, but we find them cubical, flat, thread-like, spindle-shaped, columnar, or irregular in outline. They are often



Comparative size of cells. The anthrax bacillus shown is among the largest of the bacteria, while the human liver cell is not large as cells go. (After Wells, Huxley, & Wells.)

modified by being compressed by other cells, but frequently if given opportunity will resume their original form when released from pressure.

Structural differences exist between plant and animal cells, the chief of which is the cellulose wall, characteristic of plants, which gives such cells the rigidity and yet the flexibility found in woody stems. Other physiological differences will be discussed in the following chapters.

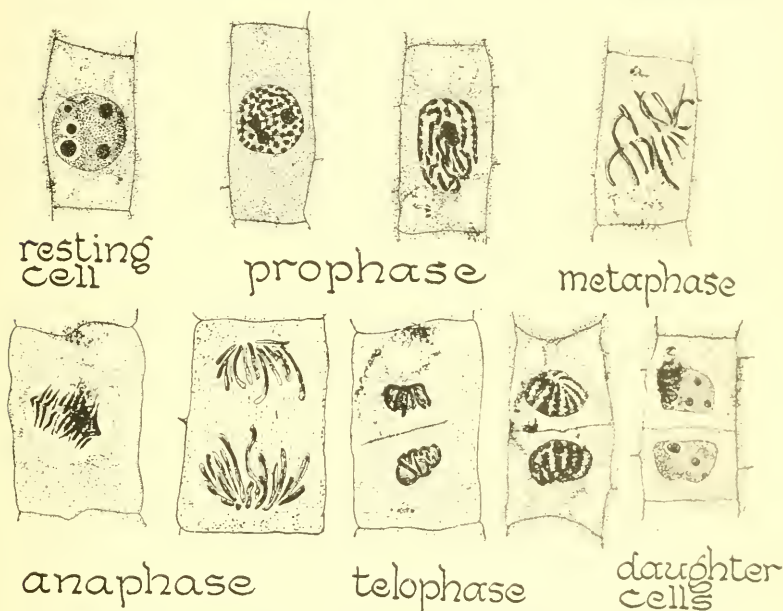
favorable, it will divide. In both plant and animal cells, the mechanism and the end results reached by cell division are similar, in that the chromatin from within the nucleus is redistributed so that the daughter cells have approximately the same amount of chromatin and eventually the same size as the parent cell from which they came. Cell division is a universal phenomenon and seems to be a part of the normal life of cells. Theories advanced to account for cell division are (1) colloidal changes in the protoplasm of which they are composed, (2) electrical changes within the cell, (3) oxidative changes within the cell, and (4) changes in surface tension. The latter can be experimentally proven by treating unfertilized eggs with certain chemicals which cause a change in surface tension and initiate subsequent cell division.

Why Cells Divide

Every cell has its limits of size and when that size is reached, if food is sufficient and conditions

How Plant Cells Divide

Both plant and animal cells are said to divide by a process of cell division called *mitosis*. In plants, the resting cell has a nucleus which contains a network of *linin fibers*, on the strands of which are found irregular chromatin granules. When the cell is activated to divide, these granules assume the form of a thickened, irregularly coiled thread called a *spireme*. This thread splits lengthwise into two threads which remain so close together that for some time they appear as one, finally splitting crosswise into a number of *chromosomes* that



Mitosis in plant cells. Read the text and explain the diagram.

are constant in number in all cells of a given species. While this process is going on there has appeared in the cytoplasm on opposite sides of the nucleus two caplike masses of delicate fibers, which later will give rise to the so-called *spindle fibers*. Now the *nuclear membrane* disappears and the fibers grow into the center of the nucleus, where some become attached to the chromosomes while others join with fibers from the opposite side or pole. This series of changes is known as the *prophase*. These two cone-shaped masses of fibers form the spindle, while the split chromosomes arrange themselves

in a plane in the middle, or equator, of the spindle, this being known as the *metaphase*. Next the half or split chromosomes appear to be pulled apart by the spindle fibers so that an equal number move toward each pole, where they come to rest. These changes are called the *anaphase*.

Here the spindle fibers which extended from one pole to the other begin to thicken at the equator. The swellings grow larger, fuse, and spread out to form a delicate plate, which eventually extends clear across the mother cell. This cell plate is in the nature of a plasma membrane which splits into two, forming the new cell wall between the two new cells. The fibers of the spindle now disappear and cell division is completed. Meantime the recently split chromosomes lose their identity and again take on the netlike appearance as in the original resting cell. The last series of changes comprises the *telophase*.

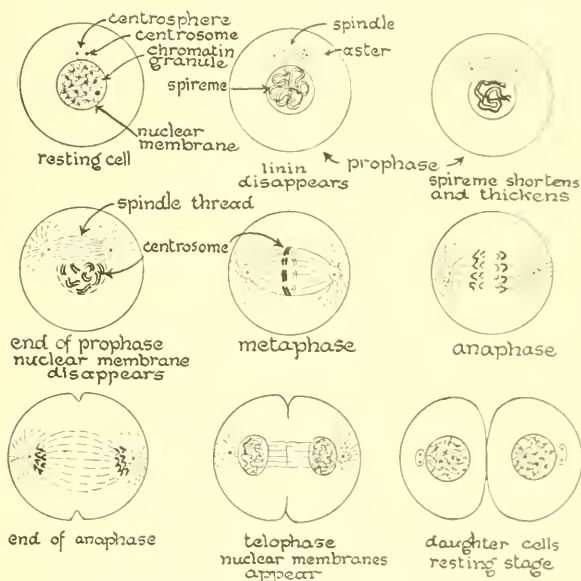
How Animal Cells Divide

The resting animal cell undergoes a similar process in division. However, in the animal cell a new structure is found, called the *centrosphere*, which is a small body lying in the cytoplasm near the nucleus. A central granule, called the *centrosome* or *centriole*, is found within this centrosphere. The centriole usually divides to form two of these granules at the beginning of mitosis. The initial stages of cell division, collectively called the *prophase*, occur when the particles of chromatin scattered throughout the nucleus take the form of the *spireme* or tangled thread. This thread thickens and shortens and then breaks up into the individual chromosomes. The number of chromosomes for the *body cells* of the individual of a species is always constant. Among plants, for example, in the pea there are always 14, in the onion 16, and in the lily 24; while examples taken at random among animals show 4 for certain roundworms, 8 for the fruit fly, *Drosophila*, of which you will hear more later, 32 in one of the common earthworms, 200 in one of the crayfishes, 24¹ in a common locust, 24 in one of the frogs, and 48 in man.

During the formation of the spireme the threads of the future spindle are growing out from radiations, called *asters*, which appear around the centrioles. (See figure on page 143.) As the process continues the two

¹ This is not quite exact, for it has been found that in some animals at the time when the chromosomes are reduced in number in the process of maturation (see page 429), there is an even number in the female sex cells but an odd number in the male sex cells or vice versa.

centrioles move farther apart, the spindle fibers elongate, the nuclear membrane disappears, some spindle fibers appear to attach to the chromosomes, and gradually the longitudinally-split chromosomes collect at the equator of the spindle. The next step in mitosis, known as the *metaphase*, is the arrangement of the chromosomes, with each split body on opposite sides of the equator of the spindle. Then the two sets of chromosomes begin to move toward the opposite poles of the spindle, the fibers which are attached to them getting shorter and shorter. At this time comes the first external appearance of cell



Mitosis in animal cells. Compare this diagram with that on page 111.

division, a slight constriction appearing in the cell body. The constriction in the cell becomes more evident and, as the process continues, the chromosomes become grouped so as to form the new nuclei of the two daughter cells. These progressive changes are collectively known as the *anaphase*. In the final stage, or *telophase*, the two sets of chromosomes gradually lose their individuality and become little masses of chromatin grouped on linin fibers in the new nuclei around which a nuclear membrane is formed. Meantime the constriction in the cell has gone far enough to form two daughter cells—the new separating partition appearing along the line of the equator

of the spindle. The centriole in many daughter cells divides immediately into two, although in some cells it remains as a single body until a new mitosis begins.

Tissues

Cells form aggregates called tissues, examples of which may be seen in the woody cells making up the greater part of the stem of a plant; the elongated cells in this same stem which form the *conducting tissue*; the flat protective cells covering the outside of the leaf, called collectively the *epidermis*; and the large columnar cells filled with green chloroplasts that form the *parenchyma layer* directly under the epidermal cells. In our own body, we find numerous examples of familiar tissues set apart for doing some particular work, such as the *epithelial*, or protective, tissues; the *connective* tissues, which serve to bind the various groups of cells together; the *muscular* tissues, of several kinds; the *supporting* tissue cells, which help to build the bones; *glandular* tissues; the *nervous* tissues of several kinds; and the blood, which, though fluid, yet contains cells, and is classed as a *circulating* tissue.

The Tissues in Plants

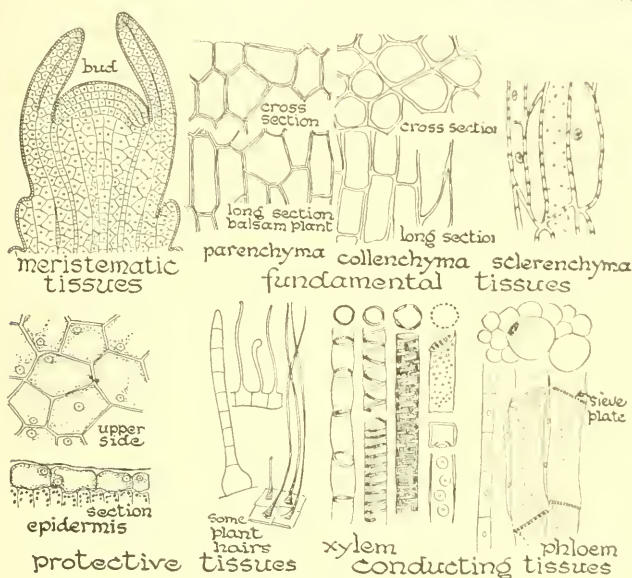
It is a difficult matter to make a classification of tissues that will fit all plants and yet be simple enough to use at this stage of our biological knowledge. But the following will give us a general survey which can later be expanded by the student of botany.

THE MERISTEMATIC TISSUES. These cells in general are small, thin walled, and rich in protoplasm. They are found in the rapidly growing parts of plants, the buds, the tips of the roots, and in growing layers. They represent the primitive and embryonic tissues.

THE PROTECTIVE TISSUES. Such are the epidermal cells covering leaves. These are often waterproofed with a waxy material called *cutin*. Such layers are found on the outside of the stem, root, and even the fruit, forming a protective covering. In the stem and the root, the epidermis is often replaced by a layer of corky cells, while on leaves, stems, and flowers the epidermal cells frequently develop hairs or scales, which sometimes secrete sticky substances.

THE FUNDAMENTAL TISSUES. These groups of cells form the great mass of plant tissue, such as the soft green parts of the leaf, the *pith* or *cortex* of plant stems, the soft parts of flowers and fruits. These cells differ greatly in size and shape in different parts of the plant,

but in general they are alive and act as storage cells. Some of the parenchyma cells, called collectively *collenchyma*, become thickened at the corners, as seen in a cross section, and serve as strengthening



Types of plant tissue cells.

units in the outer part of the stem. The walls of the other fundamental tissue cells become much thickened and are called *sclerenchyma* cells, which may become fibrous, helping to support the stem, while others form *stone cells* making up the covering of nuts and other hardened parts.

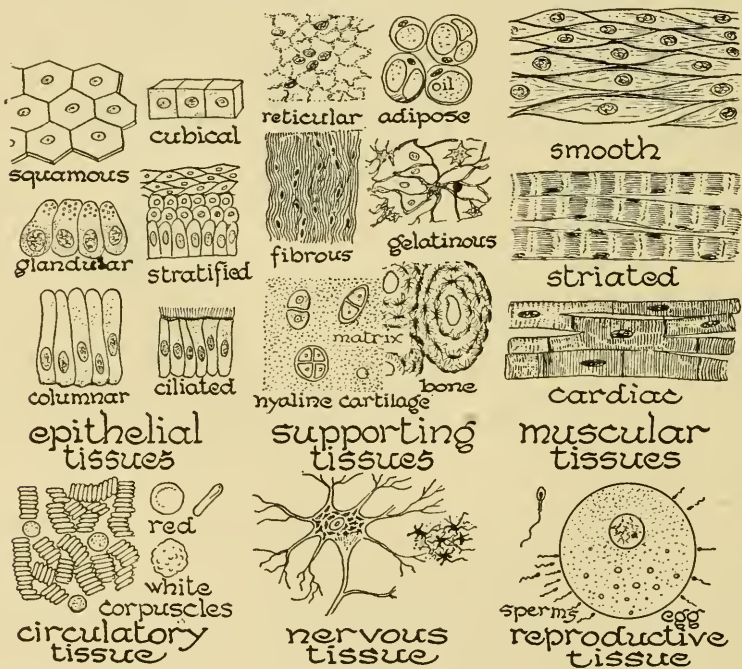
THE CONDUCTING TISSUES. In the higher plants, woody bundles of elongated cells act as tubes for the conduction of water and food substances. The water-conducting tissues are collectively known as the *xylem* and consist largely of supporting dead cells (*tracheids*) impregnated with a strengthening substance called *lignin*, and long tubular cells (*vessels*) which have lost their cross walls. Scattered amongst them are various other types of cells, including parenchyma. The tissues which conduct food materials down the stem from the leaves, where food is made, are known collectively as the *phloem*. The characteristic conducting cells of the phloem are known as *sieve tubes*, which have perforations in the end or side walls known as the *sieve plates*. Long threads of cytoplasm pass through these holes,

connecting cell with cell and making a pathway for the food substances. Small *companion cells* are attached to the sieve tubes. The phloem is also provided with parenchyma and fibrous cells, which give strength to the tubular bundle.

The Tissues in Animals

Although the histologist makes a much more detailed classification of tissues, a convenient grouping for animals is the following:

THE EPITHELIAL TISSUES. Not only do these cells form the outer layer of the animal body, but they also are responsible for the formation of such protective body structures as the calcareous shells of



Types of animal tissue cells. Into how many groups may they be classified?

clams and oysters, the chitinous covering of the insect, or the outer covering of the crayfish. These tissues line all body surfaces as well as the digestive tract and other in-pocketings of the outer body covering. They are of the utmost importance because they also form the glands of the body, structures which secrete, for example,

digestive enzymes or the waste products of metabolism, such as perspiration. They also form a large portion of many of the sense organs of the body. In shape, the cells of epithelial tissues as they lie side by side may be flat, cuboidal, columnar, or even ovoid.

THE SUPPORTING TISSUES. These tissues serve to bind together or support the various parts of the body. They include bone, cartilage, and connective tissue, and they differ from other tissues in that it is the material formed by the cells, rather than the cells themselves, that is of functional importance. In bone or cartilage, for example, the supporting portion or *matrix* is produced by the cytoplasm of cells and surrounds it. Fat cells are connective tissue cells in which the body of the cell becomes a storehouse for a drop of fat, the living part of the cell being much reduced. Pigment cells are branched irregular structures of a somewhat similar nature. Most characteristic of true connective tissues are the white non-elastic fibers that make a network in certain parts of the body, or form the glistening cords or *tendons* which connect bones with muscle, or *ligaments*, which connect bones with bones. Other forms of connective tissue that might be mentioned are the *areolar*, which forms an elastic padding underneath the skin; and the yellow elastic fibers found in the air tubes of the lungs and the walls of arteries.

THE MUSCULAR TISSUES. Motion of certain cells is produced by amoeboid movement, or by the lashing of tiny threads of protoplasm, that is, *flagella* or *cilia*. But in higher animals movement is brought about by the muscle cells in which the property of contractility is greatly developed. In higher animals, muscles are groups of highly specialized cells bound together by connective tissues. There are three kinds of muscle cells, namely, smooth, striated, and cardiac. Smooth muscle cells are long with an outer contractile fibrillar layer surrounding a central area of semifluid protoplasm containing a nucleus. In vertebrate animals, smooth muscle is found particularly in the walls of the blood vessels and the walls of the digestive tract. *Striated* muscle fibers in higher animals are groups of cells showing no cell boundaries and held together by connective tissue. They show curious cross striations and on the whole in man are under control of "the will," hence are called voluntary muscles. A third type of muscle, the *cardiac*, is striated, but involuntary in action, making up the tireless muscles of the heart.

CIRCULATORY TISSUE. Although the blood, lymph, and other fluids that serve to transport foods and wastes in the body are con-

stantly in motion, we must classify them as tissues, for they contain living cells or corpuscles of various kinds, carried about in a fluid matrix or *plasma*. These tissues are of the utmost importance to animals, as it is only by means of them that the living cells of the body receive nourishment and oxygen, and get rid of their wastes.

THE NERVOUS TISSUES. Even in its simplest form we have seen that protoplasm is sensitive and responds to stimuli. In higher animals this sensitivity and conductivity of sensations is taken over by the nervous tissues. The unit of structure is the *neuron*, or nerve cell. The elongated fibers from these cells are bound together into nerves or conducting pathways for nerve impulses. All parts of the vertebrate body, with the exception of the cartilages and epidermal derivatives, are supplied with nervous tissue, which may be said to be the master tissue of the body.

REPRODUCTIVE TISSUES. These cells which, as one author puts it, are "within the body though perhaps not of the body," form tissues, eggs and sperms, that have to do with the futures of all animals.

Why Are Living Organisms So Called?

In the preceding pages, we have referred to living things as organisms. The anatomist calls collections of tissues, which do specific kinds of work, organs. The hand is an example of an organ which is a collection of tissues. *Muscles* are attached to the *bones* by means of *tendons* and bones are joined together by ligaments. The *skin*, composed of several different kinds of tissue cells, is supplied with *blood* and *nervous* tissues, while the whole organ is interlaced through and through with other *connective tissues*. Living things are made up of organs, and we call them organisms. The living world about us, plant and animal, is a collection of organisms, some very simple, others aggregates of simple cells, still others formed of untold billions of differentiated cells, grouped into tissues forming an organism, such as an insect, a fish, a tree, or a man. Yet all these different and complex entities basically are made of the living stuff called protoplasm. In animals, this grouping of organs which are united in the performance of some general function gives us a number of organ-systems. There is, for example, the *integumentary* system, or outer body covering; the *supporting* system, which forms the body frame; the systems which have to do with the nutrition of the body, the *digestive*, *respiratory*, *circulatory*, and *excretory* systems; the *nervous* system, which controls the activity of the body; and the *reproduc-*

live system, which has to do with the continuance of life. It is on the structural development of these systems, developed to a greater or lesser extent in all of the many-celled animals, that the various groups of the metazoa are classified.

SUGGESTED READINGS

Dahlgren, U., and Kepner, W. A., *Textbook of the Principles of Animal Histology*, The Macmillan Co., 1908. Chs. I, II, and V.

Holman, R. M., and Robbins, W. W., *Elements of Botany*, 2nd ed., John Wiley & Sons, Inc., 1928. Ch. III.

Maximow, A. A., *Textbook of Histology*, edited by W. Bloom, W. B. Saunders Co., 1930.

Rather technical. Chapters I and II useful.

Stöhr, Philip, *A Textbook of Histology*, 5th ed. (arranged by J. L. Bremer), P. Blakiston's Son & Co., 1936.

Chapters I and II make excellent reading.

Wilson, E. B., *The Cell in Development and Heredity*, 3rd ed., The Macmillan Co., 1925.

The most authoritative text on the cell. Rather advanced, but with excellent figures. Chapters I and II especially useful.

ORGANISMS ILLUSTRATING BIOLOGICAL PRINCIPLES

VII

BEGINNINGS: THE LARGE GROUP OF THE SMALLEST ORGANISMS

PREVIEW. Some forms found in a drop of fresh water: Amœba, an animal cell; Euglena; Paramecium; Diatoms; Desmids; Bacteria · Functional differences between plant and animal cell · Suggested readings.

PREVIEW

Over two hundred and sixty years ago, when the Dutchman, Antony van Leeuwenhoek, examined what he called "little animals" under his homemade microscope, he made the first real exploration of a drop of water ever attempted. His microscopes were simple affairs, consisting of a single lens. They had no tube or mirror such as our microscopes of today have. When objects were examined they had to be brought into position and focus through the use of rather coarse screws.

Besides being the first person actually to see the capillary circulation of the blood (a thing that Harvey knew must be so, but which he was unable to prove), van Leeuwenhoek made numerous other physiological and anatomical observations which gave him the title of "founder of histology." One thinks of him most often as the first man who saw protozoa, unicellular plants, and even bacteria in standing water.

Let us read his own description and judge for ourselves as to what he saw. The following extract is taken from a letter written on October 9, 1676, to Henry Oldenburg, First Secretary of the Royal Society of London. It describes the finding of "little animals" in a drop of rain water.

"Of the first sort that I discovered in the said water, I saw, after divers observations, that the bodies consisted of 5, 6, 7, or 8 very clear globules, but without being able to discern any membrane or skin that held these globules together, or in which they were inclosed. When these animalcules bestirred 'emselves, they sometimes stuck out two little horns, which were continually moved, after the fashion of a horse's ears. The part between

these little horns was flat, their body else being roundish, save only that it ran somewhat to a point at the hind end; at which pointed end it had a tail, near four times as long as the whole body, and looking as thick, when viewed through my microscope, as a spider's web. At the end of this tail there was a pellet, of the bigness of one of the globules of the body; and this tail I could not perceive to be used by them for their movements in very clear water. . . .

"I also discovered a second sort of animalcules, whose figure was an oval; and I imagined that their head was placed at the pointed end. These were a little bit bigger than the animalcules first mentioned. Their belly is flat, provided with divers incredibly thin little feet, or little legs, which were moved very nimbly, and which I was able to discover only after sundry great efforts, and wherewith they brought off incredibly quick motions. The upper part of their body was round, and furnished inside with 8, 10, or 12 globules: otherwise these animalcules were very clear. These little animals would change their body into a perfect round, but mostly when they came to lie high and dry. Their body was also very yielding: for if they so much as brushed against a tiny filament, their body bent in, which bend also presently sprang out again; just as if you stuck your finger into a bladder full of water, and then, on removing the finger, the inpitting went away."

His description of the cause of movement in his little creatures is amusing, yet it shows that he saw cilia plainly and estimated their size quite clearly.

"But many of the things we imagine, and the natural objects that we inquire into, are very insignificant; and especially so, when we see those little living animals whose paws we can distinguish, and estimate that they are more than ten thousand times thinner than a hair of our beard; but I see, besides these, other living animalcules which are yet more than ten thousand times than a hair of our beard; but I see, besides, these other living animalcules which are yet more than a hundred times less, and on which I can make out no paws, though from their structure and the motion of their body I am persuaded that they too are furnished with paws withal: and if their paws be proportioned to their body, like those of the bigger creatures, upon which I can see the paws, then, taking their measure at but a hundred times less, it follows that a million of their paws together make up but the thickness of a hair of my beard; while these paws, besides their organs for motion, must also be furnished with vessels whereby nourishment must pass through them." ¹

Van Leeuwenhoek was made a member of the Royal Society for his clear reports of what he saw and at his death he had sent the Society a

¹ Dobell, C., *Antony van Leeuwenhoek and his "Little Animals,"* pp. 118 and 180, Harcourt, Brace and Co. By permission of the publishers.

case containing 26 of his microscopes, a gift which was later lost. One of the few remaining of the 419 lenses put up at auction after van Leeuwenhoek's death was recently examined by an expert who reported that the biconcave lens that he inspected "was very good indeed" and proved that its maker had attained "a very high degree of proficiency in grinding extremely small glasses."

With the modern microscope of the college laboratory, infinitely better work can be done than with this old pioneer. The best of van Leeuwenhoek's lenses are said to have magnified not more than 270 diameters, while the "high dry" power of the average modern microscope gives a magnification of about 440 diameters, so that the college freshman today has a far better physical equipment than did this famous Dutchman. He also has much more. In the years that have intervened between the time of van Leeuwenhoek and the present, patient observations of minute forms of life have been made by hundreds of scientists whose results may be found in these pages and in other books suggested for collateral reading. With this introduction the student might begin the study of simple organisms in some such way as Antony van Leeuwenhoek did, by examining a drop of pond water.

Some Forms Found in a Drop of Fresh Water

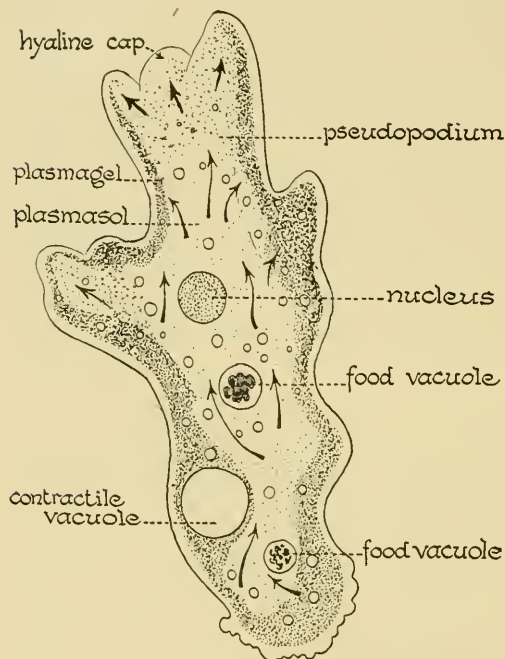
The pages that follow will serve to give us a slight acquaintance with some of the simplest plant and animal forms that are likely to be met in the examination of a drop of pond water or water from a laboratory aquarium. In addition to the unicellular organisms, scores of other higher forms are likely to be seen. Countless protozoa, including the many tiny species of monads, dart across the field of the microscope; others many times larger, with their highly specialized cell parts, as *Euplotes* or *Stylonychia*, may be found browsing on tiny plants. Frequently one also encounters threads of the filamentous algae, *Zygnema* or *Spirogyra*, while debris, consisting of tiny bits of wood, sand grains, and the glasslike cases of diatoms and desmids, may abound.

Many tiny crustaceans, water fleas, and copepods are usually present, and in addition one finds the easily recognizable rotifers, with their whirling wheels of cilia, their prominent grinding organ or *mastax*, and their slender toelike posterior foot by means of which they often become attached to solid objects. Sometimes a small roundworm may be found working its way through the debris, while

many types of insect larvae and pupae may also be seen. This brief list includes only a few of the many new acquaintances to be found in a drop of water.

Ameba, an Animal Cell

Ameba is the classic representative of a single-celled animal which illustrates the action of living protoplasm. Found in ooze taken from the bottom of small ponds or sluggish streams, it is seen to be



Ameba proteus. The direction of progress of the cell is shown by arrows. What happens to the protoplasm in the extreme anterior end during movement. (After Mast.)

an irregular and almost transparent cell. When in motion the protoplasm of its body apparently flows out into newly formed bulging projections of the body called *pseudopodia* (Gk. *pseudo*, false; *pous*, foot). The cell body consists of two substances, an inner, more fluid, granular portion, the *endoplasm* and a more viscous area, the *ectoplasm*, on the outside. The whole Ameba is surrounded by a delicate plasma membrane. When the animal moves, the protoplasm appears to flow into the pseudopodia. According to S. O. Mast of the Johns Hopkins University,

when an Ameba is moving

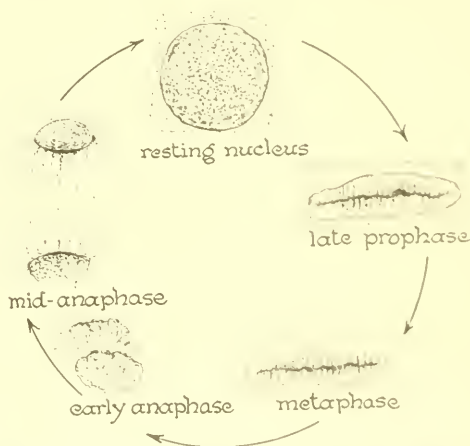
in a given direction the endoplasm sol pushes out in a pseudopodium and becomes changed to a gel, the "gel" at the other end of the cell becoming a "sol" that moves into the cell body. This illustrates a characteristic of protoplasm mentioned earlier. This cell, like others of its kind, has a nucleus containing chromatin. Certain vacuoles are present, some of which are filled with a watery fluid, others hold food in different states of digestion, while a single

vacuole, called the *contractile vacuole*, rhythmically collects and expels fluid. The function of the contractile vacuole may be to eliminate wastes from the cell, or it may have a hydrostatic function, that is, it may control the amount of water contained in the cell. Food particles are actually ingested or taken into the cell by the protoplasm which flows around the food, engulfs it, and then surrounds it with digestive fluids in a *food vacuole*.

A recent series of observations by Mast and Hanhart¹ indicate that the *Ameba* selects certain kinds of food, preferring, for instance, *Chilomonas* to *Monas*, although both are flagellates of about the same size, form, and activity. It was further shown that *Monas* was not digested in the food vacuoles, while *Chilomonas* was, and also, some organisms, such as mold spores, certain algae, and other flagellates, might be eaten but were not digested.

The process of constructive and destructive metabolism may take place in a single cell. Indigestible waste materials are passed out anywhere from the surface of the cell body, while respiration takes place by means of an osmotic exchange of the gases, oxygen and carbon dioxide, through the cell membrane.

As a result of the taking of food, the cell gradually increases in size and then divides by a process known as *binary fission*. According to a recent study by Chalkley and Daniel² the division of the nucleus shows the typical stages of mitotic division, the entire process lasting, under normal temperature conditions, about half an hour. During the process the *Ameba* is quiescent and the



Mitotic division in the nucleus of *Ameba*. (After Chalkley and Daniel.)

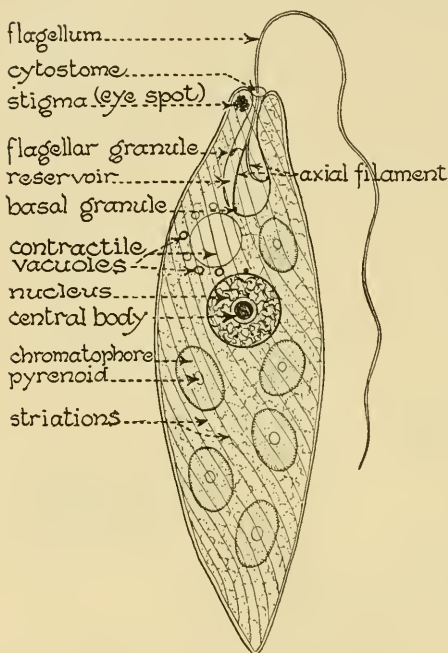
¹ Mast, S. O., and Hanhart, W. L., "Feeding, Digestion and Survival of *Ameba proteus* (Leidy)." *Physiol. Zool.*, Vol. 8, 1935. Pp. 255-272.

² Chalkley, H. W., and Daniel, G. E., "The Relation between the Time of Incubation and the Nuclear Phases of Division in *Ameba proteus* (Leidy)." *Physiol. Zool.*, Vol. 8, 1935. Pp. 592-619.

pseudopodia are relatively small. After the nucleus divides, the cell body separates into two equal parts, each of which grows into a full-sized individual.

Euglena

Although *Ameba* is usually looked upon as the simplest of all animal cells, there is another group of organisms containing equally simple forms, making up a large proportion of the microscopic plankton of the ocean and bodies of fresh water. This group, which comprises one of the classes of the Phylum Protozoa, includes the *Mastigophora*, or flagellates, cells that move by means of one or more long, whiplash threads of protoplasm. Certain of the *Mastigophora* bear a close relationship to plants, and the organism *Euglena*, selected as a representative of the group, is often claimed as a plant cell by botanists. *Euglena* may be found in shallow and sometimes temporary freshwater ponds, where it often grows with such rapidity as to give a dull greenish color to the water. When unfavorable conditions set in, the organism settles to the bottom, becomes covered with a resistant coat or cyst, and is only recalled



Euglena viridis. Read your text and give the functions of each of the structures shown. Note that the drawing makes the cell appear flat whereas in cross section it is oval. What evidence of holophytic nutrition is seen in this diagram? (After Hegner.)

to active life by a recurrence of favorable environmental conditions.

Some species of *Euglena* have conspicuous spiral markings on the surface of the body, which is roughly ovoid, with a depression at the anterior end, called the gullet. A single flagellum has its origin near the base of the gullet, in the form of a long axial filament anchored in the protoplasm, that gives the filament free movement. By

means of a rotary movement of the flagellum, the cell is pulled forward on a spiral course, which is caused partly by the way the flagellum moves and partly by the irregular shape of the cell. At the same time a current of water is swept into the gullet, bearing with it particles of potential food. The membranous covering of the body allows the shape of the cell to change, often moving by what is known as euglenoid motion, that is, by a wave of contraction over the whole body, thus causing a slow movement like that characteristic of *Ameba*.

Although some species of *Euglena* appear to ingest the food particles that are swept into the gullet, the ordinary nutrition is the same as that of a green plant. The inner protoplasm of the cell is filled with chloroplasts (chromatophores) by means of which the raw materials, water, carbon dioxide, and mineral salts, are synthesized into food, thus storing the energy of sunlight. Different species of *Euglena* are sensitive to different degrees of sunlight and are found to turn towards a source of light, the anterior part of the cell, which contains a red "eyespot," being most sensitive to the light stimulus. When they are exposed to strong sunlight, they change their direction, coming to rest in an area of moderate or "optimum light." Respiration is carried on as in any other unicellular form by exchange of gases through the membrane covering the body. During the period when starch is being made in the sunlight enough oxygen is released within the cell body to supply its needs. Excretion of waste products appears to be taken care of by a number of very small contractile vacuoles, that collect fluids from the cell, eliminating them periodically into a small reservoir which empties into the gullet. The individual cell in some respects acts like a plant, and in others like an animal. It is a borderline representative, and as such must be regarded as a very primitive organism.

Reproduction takes place as in other simple forms by *fission*, the free-swimming cell splitting lengthwise. The split begins at the anterior end, the two new cells finally having the same structures as are found in the parent cell. In some species of *Euglena* that encyst, the cell divides by fission during the quiescent period, so that two or more cells are eventually released from the cyst. In some instances as many as 32 have been released from a single cyst.

Paramecium

Although protozoa are single cells, some representatives of the phylum are much more highly specialized than the simple *Ameba*, or

Euglena. These living cells may often be seen with the naked eye as whitish specks, moving slowly near the surface of a laboratory hay infusion that has been standing for some time. There are several different species commonly found, some larger than others, although

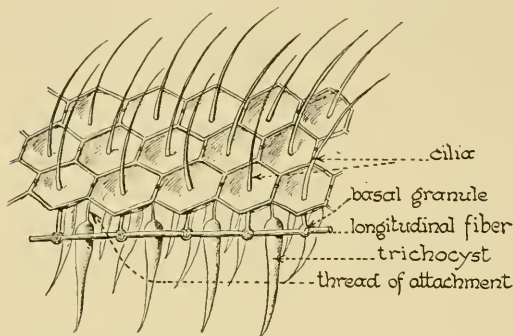


Diagram showing structure of the pellicle in *Paramecium multimicronucleata*. Under high power of the microscope the pellicle is seen to form minute hexagonal areas, from the center of each of which a cilium protrudes. The cilia arise from basal granules (microsomes) which are located on strands of protoplasm (longitudinal fibers). Where do the trichocysts lie with reference to the cilia? Where are the openings through which the trichocysts are discharged? (After Lund.)

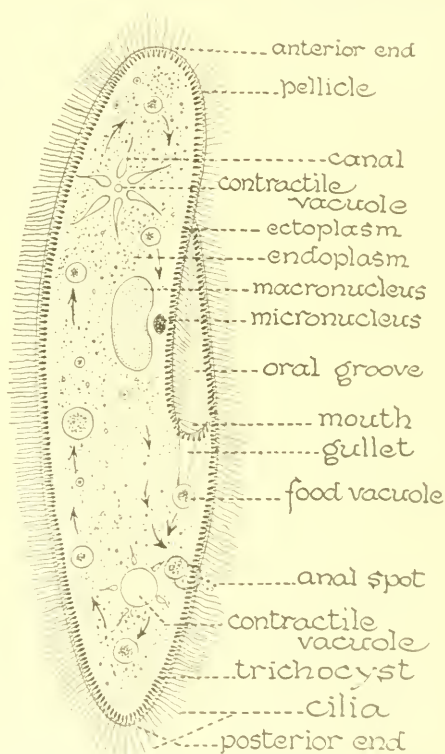
in a drop of infusion much variation in size within the same species may be found. The class, *Infusoria*, contains a large number of forms, one of which, *Paramecium*, or the "slipper animalcule," is very common. It has a somewhat flat, elliptical body with the anterior thinner end more blunt and the broader posterior end more pointed. The cell body of *Paramecium* is almost transparent and is made up of an outer, non-granular layer, the *ectoplasm*,

and an inner semifluid, granular layer, the *endoplasm*. The ectoplasm is covered with a delicate, elastic, but lifeless covering called the *pellicle*. Under it is the living cell membrane and through the pellicle project numerous threads of protoplasm, the *cilia*, which are distributed over the surface of the body in regular rows. The cilia are quite uniform in size except at the posterior end of the cell, where they are a little longer. It is by means of a lashing movement of these cilia that locomotion takes place. Embedded in the clear ectoplasm are also found numerous defensive structures, called *trichocysts*. Under certain conditions, delicate filaments or threads are discharged from them which serve as organs of offense and defense. It is believed that they may contain minute quantities of poison which paralyzes other protozoa.

On one side a depression, the *oral groove*, runs diagonally from the anterior end of the body to about the middle. This oral groove ends in a *gullet*, which in turn leads to the interior of the cell. The

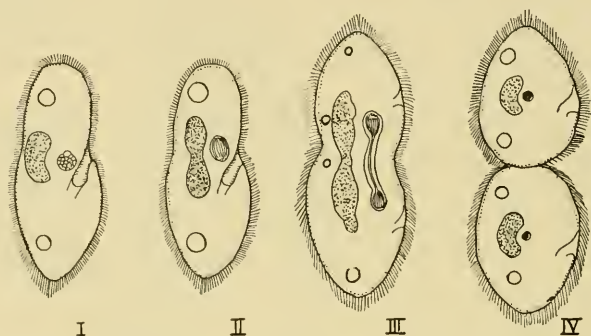
diagonally beating cilia which cover the body cause the rotation of the Paramecium on the longitudinal axis. Since the cilia in the oral groove are longer and capable of more vigorous motion, the body tends to swerve toward the left. As the water passes down the oral groove towards the gullet, the waving *undulating membrane*, formed of cilia fused together, guides particles of potential food down the gullet by means of its wavelike motion. At the inner end food vacuoles are formed within the body. The food vacuoles and other granular inclusions shift about in a definite course within the endoplasm of the cell. Gradually the food particles within a given vacuole are digested by means of enzymes formed in the endoplasm and released into the food vacuole. The digested food material is absorbed into the protoplasm, there to build up living matter or to be used later in the release of energy. Food wastes are passed out of the cell through the *anal spot*. Excretion of wastes may also take place through the cell-membrane by diffusion, or through two contractile vacuoles, one at each end of the cell, which consist of a central cavity with canals radiating out from it into the endoplasm.

Many experiments have been made to test the sensitiveness of Paramecium to various stimuli. As in other living cells responsive to stimuli, factors of the environment have a distinct influence upon its movements. Paramecium swims in a spiral course partly as a result of its shape and the arrangement and diagonal beating of the cilia, and partly on account of the anteriorly



Internal structure of *Paramecium caudatum*. The cilia cover the entire surface of the cell and are somewhat longer at the posterior end.

pointed groove which turns the cell to the left as it progresses through the water. When moving into an unfavorable environment or hitting against a solid object, *Paramecium* reverses the direction of its ciliary lashings, backs away, and goes forward again in a slightly different course, repeating the performance until the obstacle is eventually avoided. Other reactions take place with reference to light, gravity, heat, dissolved chemicals, electricity, and water currents, all of which, whether positive or negative, are co-ordinated by means of a so-called *neuromotor* mechanism within the cell that enables it to adjust itself to its environment. Under careful methods of staining a number of very minute fibrils may be found in the cell which arise in a central



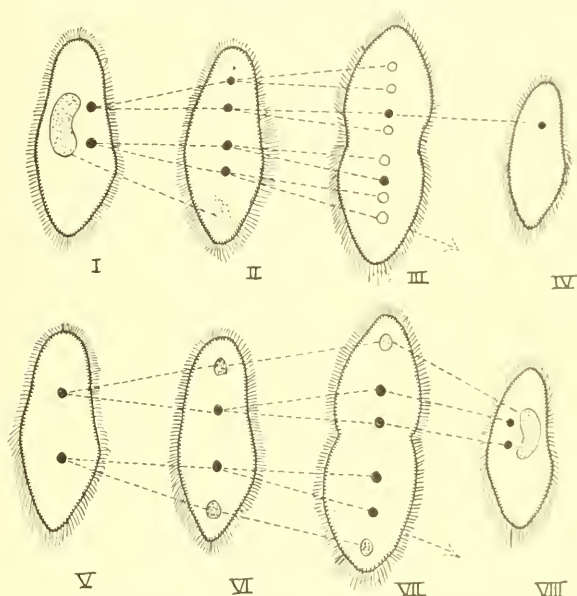
Binary division of *Paramecium caudatum*. Note the position and structure of micro- and macronucleus in I. Follow these structures to the formation of the daughter cells (IV). Do both micro- and macronuclei divide by mitosis? What other changes take place in the cells? (After Hegner.)

body near the nucleus and radiate out to the bases of the cilia. This apparatus apparently aids in co-ordinating the action of different parts of the cell.

Occupying a central area in the cell are two denser bodies, the larger, known as the *macronucleus*, has to do with the metabolic activities of the cell, while the smaller, or *micronucleus*, contains the chromatic material which is associated with heredity.

In a hay infusion *Paramecia* may be found dividing by simple fission. In this process both macro- and micronucleus elongate, and then divide. A new gullet buds off from the original one, two new contractile vacuoles appear, and the cell, which has been constricting in the middle, pulls apart to form two new cells. This process may continue for a good many generations where food is plentiful and conditions of life favorable. Woodruff has kept one culture of *Par-*

amecia in his laboratory at Yale University for thirty years, and during that period over twelve thousand generations were bred by hand. It has been observed in these cultures, however, that after 40 or more divisions have occurred, a process called *endomixis* takes place, in which the old active macronucleus is replaced by a new one made

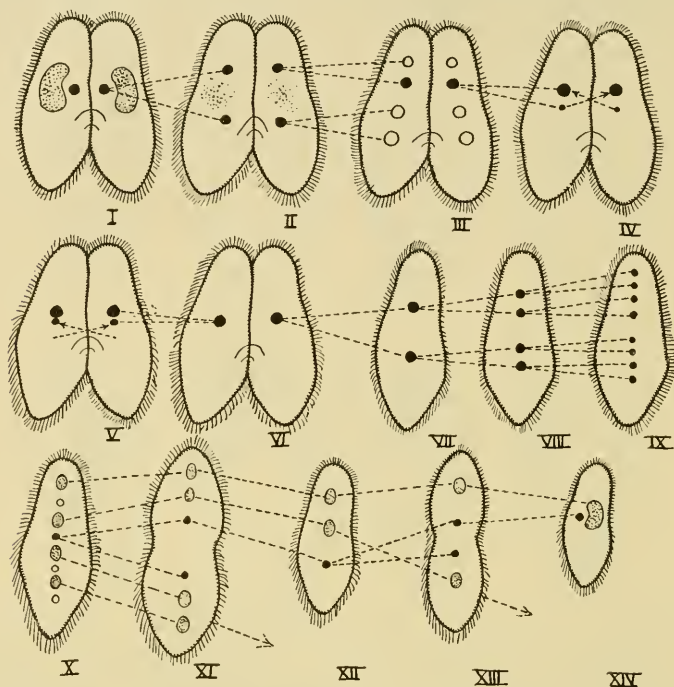


Endomixis in *Paramecium aurelia*. The normal condition of *Paramecium* is shown in I showing macronucleus and two micronuclei. Follow through the series pictured. What happens to the macronucleus? How many micronuclei are formed? What happens next? Note in IV that only one daughter cell is shown. How does this cell obtain the normal number of micronuclei? Where does the new macronucleus come from? This rhythm of cell activity seems to occur with considerable regularity every 40 to 50 generations and it gives the new macronucleus chromatin from the reserve supply held in the micronucleus. This process does not appear in all ciliates and is not believed to be necessary for normal growth. (After Hegner.)

from chromatin of the reserve micronucleus. This process is similar in many respects to conjugation, except that no foreign chromatin is added.

Under normal conditions, another process known as *amphimixis* or *conjugation* takes place somewhat resembling the sexual processes of higher animals. Two cells come to lie with their gullet surfaces next to each other and a bridge of protoplasm forms between them. While this is going on the micronucleus in each cell moves away from the

macronucleus, elongates and divides twice in rapid succession. Three of the micronuclei thus formed in each cell disappear, but the fourth one divides again. In this last division two irregular masses of chromatin are formed. This process has been likened to a similar division



Conjugation in *Paramecium caudatum*. Shortly after the conjugating pair come together with their ventral surfaces opposed (I) a protoplasmic bridge is formed, the macronucleus breaks down (II) and each micronucleus divides a second time (III). What happens to three of the four micronuclei? Compare this stage with the figure on page 429 (maturation). Next the micronuclei remaining in the cell divide into two, the smaller (migratory) micronucleus passing over by the protoplasmic bridge into the opposite cell, there to unite with the larger (stationary) nucleus (VI). Trace the subsequent divisions of the fused micronucleus (VII, IX). How do we get back to the original cell condition? (X-XIV). (After Hegner.)

that takes place in the eggs of animals, at the period known as maturation, when the sex cells are losing part of their chromatic material in preparation for fertilization of the egg by the sperm cell. The smaller mass is thought to correspond to a sperm cell of the many-celled animals, while the larger one corresponds to the egg cell. In any event, each of the smaller micronuclei migrates reciprocally over

the protoplasmic bridge, and unites with the larger micronucleus of the cell left behind. The two conjugating cells now separate, and the newly fused nucleus, composed of a male and female micronucleus, is left in each cell. Then a series of divisions of this nucleus take place until eight nuclei are formed, four of which become macro- and four micronuclei. Three of the micronuclei next disintegrate, leaving the cell with four macro- and one micronucleus. The latter divides again and with it the cell, so that two cells result, each with a micro- and two macronuclei. A second division leaves the daughter cells each with a single macro- and micronucleus, which, thus rejuvenated, start off on a series of several hundred cell divisions until another period of old age comes on, when conjugation or endomixis is repeated.

Diatoms

These beautiful microscopic plants, sometimes called "jewels of the plant world," are among the most numerous of the one-celled plants. Over 2000 species have been identified and named. They form one of the most abundant components of plankton in both fresh and salt water, and are also found in damp earth and on moist rocks, where they may occur singly or massed together in groups. Certain species stick together because of a gelatinous material which they secrete. Some diatoms move with a slow gliding motion when they are in contact with solid objects, although lacking visible organs of locomotion. They secrete a glasslike shell exquisitely marked by tiny ridges and rows of extremely minute holes.

Diatoms have been, and still are, among the most abundant of living organisms. So abundant were they in past ages that large deposits of their shells exist in the form of diatomaceous earth. In California, there are deposits of diatomaceous earth lying hundreds of feet thick over an area of many square miles, while the floor of the ocean is covered with ooze made up of skeletons of diatoms, which after death sink to the bottom of the water.

This diatomaceous material is used as a basis for polishing powders, in the manufacture of bacteriological filters, and of certain kinds of porcelains and glass.

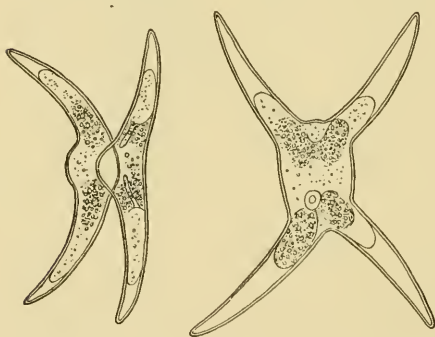


The diatom *Nitzschia* (a) valve side, (b) girdle side, showing the relation of the valves. The nucleus and the two ribbonlike chloroplasts are not shown (After Pfitzer.)

One of the most common diatoms found in pond water is *Navicula*. In this form the cell wall consists of two valves, one of which fits into the other. The part that fits over the inner valve is called the *girdle*. The cell appears quite different in structure when seen from the valve side or the girdle edge. In the latter view, a bridgelike mass of protoplasm containing a nucleus appears, while in a valve view a line running down the center, called the *raphe*, is seen, that shows three tiny spots, one in the middle and one at each end. A mucilaginous material exudes through a series of pores which form the base of the raphe. *Navicula* has two chloroplasts, colored yellowish-brown by a pigment called *carotin*. These can be seen best when the cell is viewed from the flat side. At the time of cell division, the chloroplasts first increase in size, pushing the two valves apart so that they barely touch. Then the nucleus, chloroplasts, and cytoplasm of the cell divide, an inner valve forming for each cell. Each of the new cells thus formed is much smaller than the parent cell.

Desmids

Another one-celled form common in fresh water is the bright green desmid, *Closterium*. Like diatoms, desmids are of various shapes and sizes. They are beautiful symmetrical structures with



Closterium. Two cells undergoing conjugation.

large, bright green chloroplasts, which may be lobed, starshaped, or platelike. The cell wall is thin and transparent, the granular protoplasm within being obscured by chlorophyll, but the nucleus, in the center of the cell, may be easily recognized.

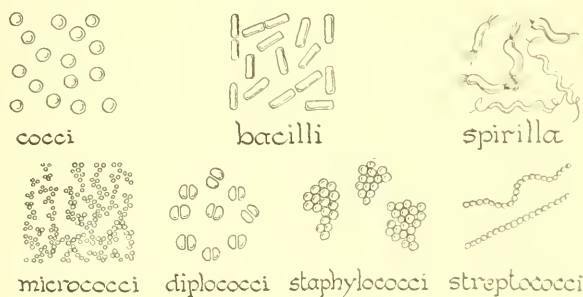
Desmids divide by a simple transverse splitting, forming two cells, each new desmid consisting of half of an old cell from which an entire cell is formed. In addition, a process of *conjugation* takes place, in which two cells come together, each sending out a protoplasmic protuberance that forms a connecting canal. The contents of the two cells meet in this tube, fuse, and form a single cell which grows a thick wall, whereupon it remains as a dormant *spore* or *zygote* until

conditions are favorable for germination. When the zygote does germinate, two new individuals come directly from it.

Many other forms of algae may be found in fresh and salt water. Some, like *Scenedesmus*, occur in colonies, their end cells being often provided with characteristic spines. Another colony of green cells, *Pediastrum*, made up of a flat plate of sixteen cells, is also frequently seen. These are only a few of the many forms of green algae that may be found in a drop of water debris taken from a quiet pond bottom.

Bacteria

Various kinds of bacteria are common in a drop of pond water or hay infusion. They are sometimes seen moving through the water, but more often are massed together in a scum covering the surface.



Forms of bacteria.

of the water. Three large groups of bacteria have been established according to their shape, *coccus*, *bacillus*, and *spirillum*. The coccus or spherical-shaped bacteria may live singly, as *micrococci*. Another form, the *diplococci*, divides and remains attached so as to form pairs; a third, *streptococci*, reproduces to form chains; while a fourth, *staphylococci*, forms irregular groups of eight cells or more, resembling a bunch of grapes; *Sarcina* divides in three directions to produce cubical packets. The rod-shaped bacteria, or *bacilli*, vary a good deal in size and shape, as well as in their ability to form spores, some being very short, others many times longer than wide. The third type, comprising the *spirilla*, are curved or twisted in shape, and move through the water rapidly by spiral movement. This form can often be seen in a drop of pond water or hay infusion. Bacilli and spirilla move by means of *flagella*, protoplasmic threads

which are difficult to see except under the highest power of the microscope.

The cell wall of a bacterium is usually considered as a selectively permeable membrane, very delicate, and secreted by the cytoplasm. A gelatinous capsule may be formed by some bacteria, so that groups of them clump together in masses. Although pigments are often present, bacteria contain no chlorophyll, and consequently most of them are dependent on other organisms for their food. They feed both on living and dead organisms, using not only organic foodstuffs, such as starches, sugars, and proteins, but even leather or wood. Since their food must be liquid in order to be absorbed, they form digestive enzymes within the cell which exude to digest the food outside of the cell body.

In addition to these foods, bacteria need certain mineral salts that are found in protoplasm, water, and nitrogen in a usable form. Not all bacteria are capable of nitrogen fixing, but many obtain their supply of nitrogen for tissue building as green plants do, in the form of compounds of ammonia or nitric acid.

The chromatin material is scattered through the cell, there being no distinct nucleus in most bacteria. Bacteria need moisture, a favorable temperature, and food, in order to grow. Under favorable conditions they multiply with great rapidity by simple fission. Under unfavorable conditions, many bacterial cells can contract, lose considerable water, and form resistant coats, thus making *spores*, which can stand extreme conditions of dryness and temperature. While bacteria are usually killed by heating to 100° C., some spores can withstand this temperature for long periods.

Functional Differences between Plant and Animal Cells

A comparison of the several types of unicellular organisms described might seem at first to show hard and fast distinctions between plant and animal cells. Although chlorophyll is associated with plants, it is sometimes found in borderline animals, while many plants, such as the fungi and bacteria, lack chlorophyll. Locomotion is not exclusively an animal characteristic. Some animal cells, as *Vorticella*, are fixed during a part of their life history, while many unicellular plants move freely through the water. Other plants, although fixed for part of their lives, produce sex cells that are motile in water. The greatest difference exists in methods of nutrition. In the green plant cell, for instance, food substances are made inside the cell in the presence of

sunlight while in animal cells, food is made outside and has to be absorbed before it can be used. The method of nutrition used by the green plant is called *holophytic*, and that of the animal cells, *holozoic*. The differences between these two types of nutrition are summed up in the table below.

ANIMAL CELL	PLANT CELL
No chlorophyll	Chlorophyll present
Cannot make organic foods	Can synthesize organic foods out of raw food materials
Only source of energy is organic food	Source of energy is the sun
Ingests solid food	Cannot ingest solid food
Usually moves about after food, therefore greater <i>destructive</i> metabolism	Does not ordinarily move about, and uses sun's energy, therefore greater <i>constructive</i> metabolism
Depends on other organisms for food	Supplies other organisms with food

SUGGESTED READINGS

Calkins, G. N., *Biology of the Protozoa*, Lea & Febiger, 1926. Chs. I, III, and IV, especially.

Dobell, C., *Antony van Leeuwenhoek and his "Little Animals,"* Harcourt, Brace and Co., 1932.

The entire book, which contains excellent translations of most of the original letters of van Leeuwenhoek, is well worth reading. It is a most authentic picture of this interesting Dutchman and his times.

Giltner, W., *Textbook of General Microbiology*, P. Blakiston's Son & Co., 1928. Ch. III.

Holman, R. M., and Robbins, W. W., *Elements of Botany*, 3rd ed., John Wiley & Sons, Inc., 1936. Ch. X.

Locy, W. A., *Biology and Its Makers*, Henry Holt & Co., 1908. Ch. V.
An excellent historical survey.

Needham, J. G., and Lloyd, J. T., *Life of Inland Waters*, 2nd ed. Charles C. Thomas, 1930. Ch. IV.

Excellent descriptions and illustrations of the life found in pond water.

Singer, C. J., *The Story of Living Things*, Harper & Bros., 1931. Ch. IV.

An interesting and authentic history of biology.

Ward, H. B., and Whipple, G. C., *Fresh-Water Biology*, John Wiley & Sons, Inc., 1918.

This book is invaluable for reference. Chapters VI, IX, and XVII are especially useful.

VIII

THE DEVELOPMENT OF SEXUALITY IN PLANTS

PREVIEW. The beginnings of sex in the algae · Oedogonium · A representative fungus · Alternation of generations in the plant kingdom · Suggested readings.

PREVIEW

The one unescapable fact that stands out in the observation of plants and animals in the world about us is the remarkable variety among living things. They range from tiny forms too small to be seen with the unaided eye to huge organisms such as elephants or trees.

The biologist is not satisfied with random looking. He looks for certain things, tries to interpret what he sees, but as Thoreau once said, "We must look a long time before we can see." One of the striking facts already noted in the Roll Call of forms of life is that both plants and animals may be placed in groups having similar characters, and that these groups arrange themselves in a series of gradually increasing intricacy of structure, which goes hand in hand with an ever increasing complexity in functions. Simple plants or animals do things simply. Almost any part of the one-celled Ameba can do any part of the work of the cell although lacking organs found in higher forms. More refined ways of doing things, and a more efficient division of work, come with increasing complexity of organic structure. The true investigator is ever alert to find forms that illustrate this increasing division of labor, and is always asking why and how such things come about. Biologists have picked out certain representative forms that clearly suggest certain facts and principles that are worth knowing. It is possible, for example, through the study of some simple forms of organisms, such as the Thallophytes, to discover the beginnings of sexuality in plants.

The Thallophytes include most of the simplest plants and are divided into two great groups, algae and fungi, the latter containing no chlorophyll. While there are six classes of algae, four, namely, the blue-green, the green, the brown, and the red, are classified largely on color. All of the four groups are essentially water-loving plants, showing in many ways that they are simple and rather primitive organisms. In size they range from tiny uni-

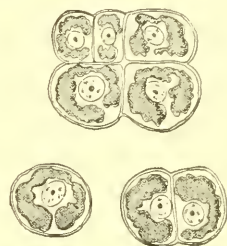
cellular forms to some of the great brown seaweeds, or kelps of the California coast which may be several hundred feet in length. Ascending the scale of increasing complexity in structure, we find the appearance first of sex cells and later of sex organs evolved to form and protect these sex cells.

By selecting other representatives from the higher plant groups, such as mosses, ferns, and flowering plants, we can follow this evolution of sex through the entire plant kingdom. The pages that follow will at least give us a start on the answer to the question: How and where does sex originate in plants and what is its meaning?

The Beginnings of Sex in the Algae

Pleurococcus, or *Protococcus* as it is sometimes called, is one of the simplest of all living plants, familiar to most of us as the green "moss" usually seen on the north side of trees. Indians used it to find their direction through the forest, as persons lost in the woods do today. Its habitat suggests that the life of the plant has direct relation to moisture, temperature, and light. It would be injured by the direct rays of the sun, because some rays such as those of ultraviolet light are injurious to unprotected protoplasm.

The cell of *Pleurococcus* is very simple as seen under a microscope. It is found single, in twos, threes, fours, or flat colonies of several cells hanging together. Examination of a single cell discloses the presence of a thin wall surrounding a mass of green protoplasm, the *protoplast*, which almost completely fills the cell. If a drop of iodine solution is placed under the coverslip, the detailed structure of the cell becomes more evident. The nucleus is completely surrounded by one large, spherical *chloroplast*. The cell is a complete entity, in spite of the fact that it is often attached to other cells. Physiologically it is able to carry on all the functions of a living green plant, making food, and digesting it as well as absorbing food and water. It grows to a certain size and then reproduces by simple fission, part of the mother cell going into one daughter cell and part into the other. Theoretically the



Reproduction in *Pleurococcus*. Each cell is considered as an individual, although colonies (seen above) may be formed. The protoplasm of the cell body is not shown, the single chloroplast being surrounded by protoplasm in active cells.



A *Spirogyra* cell showing the spiral chloroplast containing pyrenoids, and the nucleus.

protoplasm of the pleurococcus is immortal, since it passes from cell to cell by means of cell division.

Spirogyra is one of the multicellular green algae. It is a slimy thread, called "pond scum," found near the surface of a pond, often buoyed up by bubbles of gas which it forms. The filamentous plant body consists of several cells joined end to end, each with a characteristic spirally-banded chloroplast.

Examination of a single cell shows a colorless cell wall, the cytoplasm of the cell mostly adhering to its inner surface. Strands of cytoplasm radiate from a central colorless nucleus, which is suspended in a large vacuole or sap cavity. The most characteristic feature is the large twisted chloroplast, on which are scattered many *pyrenoids*, bodies which contain some of the starch manufactured by the chloroplast. Individuals grow in size by forming, through transverse division of the cells, longer or shorter filaments, depending upon the environmental conditions.

At certain times in the year, the plants form resting spores called *zygospores*. Two adjoining filaments come to lie parallel, the cells opposite to each other sending out bulging outgrowths which meet to form a connecting tube. Meantime, owing to the dissolving of the cell wall at the end of the outgrowths, water gets inside of the cells, so that they show signs of plasmolysis, rounding up into ovoid masses. Curiously, however, the cells of one filament remain stationary, while the cell contents from the other filament move over through



Conjugation of *Spirogyra*. Explain what happens. (After Coulter.)

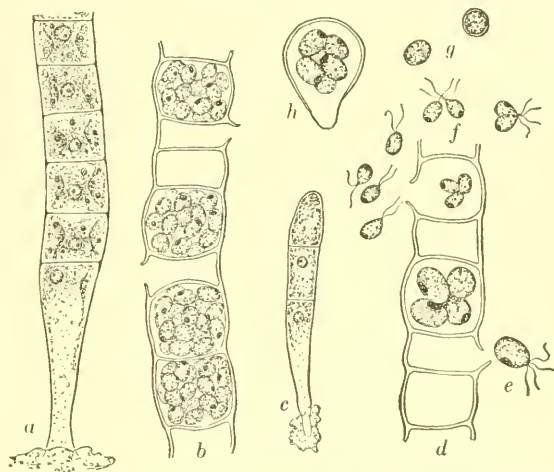
the tube and fuse with the quiescent cells. When this fusion takes place, the nuclei unite so that a single resting cell is formed, called the *zygote*, which develops a thick wall, very resistant to drought and cold. The zygote is heavy enough to sink to the bottom of the pond when the rest of the filament dies, and under favorable conditions will germinate, giving rise to a new filament.

Since these cells from different filaments join or fuse, somewhat after the manner of conjugation in *Paramecium*, we think of them as sex cells, or *gametes*. Although the two cells are of the same size, yet one is active and the other passive. In higher plants and animals, the active cell is referred to as the male gamete, or *sperm*, and the non-active cell as the female gamete, or *egg*. A comparison of *Spirogyra* with higher forms suggests a very simple type of *sexual reproduction*, known as *conjugation*.

In another filamentous form, *Ulothrix*, certain cells are modified to become free-swimming *zoospores*, provided with four cilia which

may swim about for as long as an hour before settling down. It is obvious that such a free-swimming cell may plant a new individual at some distance from the original filament. Gametes of *Ulothrix* are also formed as free-swimming cells, all alike, having two cilia instead of four. These gametes fuse by conjugation and produce a zygote, which, like that of *Spirogyra*, has a thick resistant wall, and is capable of developing even after exposure to very unfavorable conditions.

In the formation of the conjugating gametes of both *Ulothrix* and *Spirogyra* a significant thing happens to the nuclei of the cells before



Ulothrix: a, base of filament with holdfast; b, filament producing zoospores or gametes; c, young filament developed from zoospore; d, filament discharging zoospores and gametes; e, an escaped zoospore; f, escaped and pairing gametes; g, zygospores; h, zygospore producing zoospores by reduction division. (a-g, After Coulter; h, after Dodel-Port.)

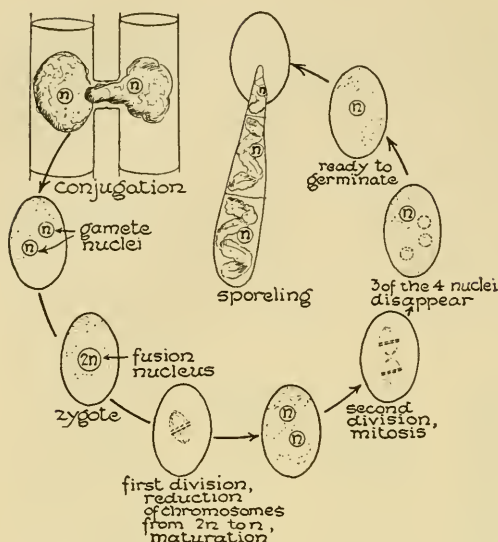


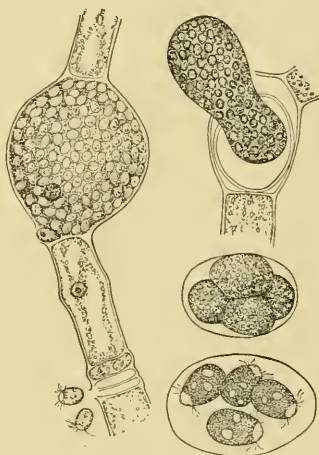
Diagram to show how reduction division takes place in the zygote of *Spirogyra*.

the number of chromosomes is halved. We speak of the single number of chromosomes as *haploid* and the double number, which comes with the union of the two gametes, as *diploid*.

they conjugate. By a series of divisions, such as is shown in the diagram, the number of chromosomes in the nuclei of the zygote, resulting from the union of the two gametes, is reduced to half this number. If some such device as this were not used, every time sex cells united, the number of chromosomes would be doubled. However, by this so-called *reduction division* during the formation of the gametes, which occurs in both plants and animals,

Oedogonium

In another of the filamentous algae, *Oedogonium*, there is the first appearance of two kinds of sex cells. This alga reproduces by zoospores and in addition forms two sex organs, structures called *antheridia*, which produce a number of ciliated sperm cells and *oögonia*, the latter holding a single egg cell. The sperm cells swim through the water from the antheridia, one uniting with the egg cell, and almost immediately a thick wall is formed about the fertilized egg. This *oöspore* does not produce a new plant directly, but gives rise to zoospores, which in turn eventually become new plants.



Life history of *Oedogonium*.

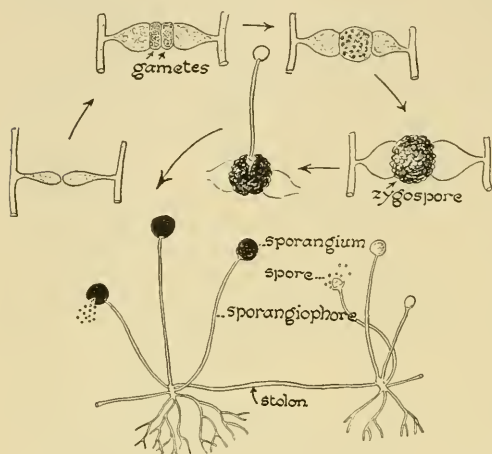
Another form of *Oedogonium* forms antheridia and oögonia on separate filaments, the male filament being much smaller than the female filament. Thus the filamentous algae illustrate three big ideas, namely, division of labor, development of sex, and reduction of chromosomes.

In the simplest plants all cells tend to do the same work, but in the more specialized algae there is a differentiation of work and an accompanying differentiation of cells to accomplish it. In the *development of sex* and of structures to take care of the sex cells, as found in the forms described, the contribution of the sex cells seems to be to provide a greater vigor to the offspring, especially when the sex cells come from different individuals. Most important of all is the fact that cells which fuse, as in the case of the sex cells, must have some way of reducing the number of their chromosomes, else they would be doubled each time two sex cells united. This is accomplished by the *reduction division* referred to above, by which process the number of chromosomes, doubled at the time of fertilization, is halved. This reduction process occurs in both plants and animals, and although in plants it occupies a different place in the life cycle, its ultimate effect is the same in both cases.

A Representative Fungus

Bread mold, *Rhizopus nigricans*, one of the most common of the fungi, may easily be grown in the laboratory by exposing a moist piece of bread to the air for a few moments. Mold spores are so numerous everywhere that under ordinary conditions a growth of mold will be evident within one or two days, first appearing as a white, fluffy growth that rapidly covers the surface of the bread. This is the *mycelium*, which consists of branching tubelike filaments, or *hyphae*, containing many nuclei, but without cross walls. The absence of chlorophyll shows the inability of the mold to make its own foods and explains why the mycelium sends down into the bread, root-like branches called *rhizoids*, that secrete enzymes, by means of which the food substances in the bread are digested. Some of the hyphae form long branches called *stolons*, which run along the surface of the bread, forming new plants. At points where rhizoids are developed, there arise later numbers of erect branches, or *sporangiophores*, on the tips of which are developed *sporangia*, or spore-bearing organs.

Great numbers of tiny spores are produced by division of the dense terminal portions of the sporangiophores. As a sporangium becomes mature an outer wall is formed and the spores turn black in color.



Reproduction in bread mold (*Rhizopus nigricans*). Read the text and then explain the diagram.

When this outer wall breaks, the minute spores are scattered far and wide by air currents.

Molds also reproduce sexually, by means of conjugation. *Rhizopus* has two different strains of mycelia, one of which is called a plus (+) and the other a minus (−) strain. If hyphae of two such strains come in contact with each other, zygospores are formed. Short, club-shaped branches are developed from the hyphae, the dense proto-

plasmic tips are cut off from the end of each by cell walls, and these "cells," each of which contains several nuclei, unite to form a zygote. The zygote with the hyphae which develop from it probably represents the diploid stage of chromosome in the life cycle, the haploid stage being reached when the spores on the sporangium germinate.

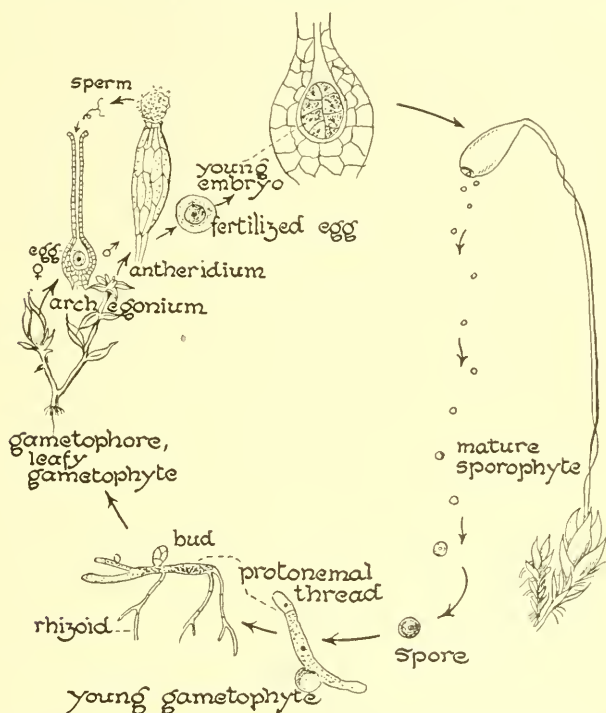
The fungi are of even more interest by reason of their method of nutrition. They are typically neither holozoic nor holophytic, since they live as saprophytes on dead organic materials. This means that they must absorb food materials which are supplied to them from outside sources after digesting them by means of enzymes, when absorption takes place through the plasma membrane of the cell.

Alternation of Generations in the Plant Kingdom

The most important difference in the life cycle between the Bryophytes or Mosses and lower forms, aside from a greater differentiation of the plant body, is the alternation of an asexual with that of a sexual generation in the life cycle. The asexual generation, which produces spores, is called the *sporophyte*, while the sexual generation, which

gives rise to gametes of two different sexes, is known as the *gametophyte*. The latter generation is the conspicuous green plant that manufactures food and serves as host for the sporophyte generation which is permanently attached to it.

The gametophyte of the simple moss, *Funaria hygrometrica*, is a short upright stalk bearing usually three spiral rows of simple leaves,



The life cycle of *Funaria*, a moss. Which stage is more prominent, gametophyte or sporophyte?

each containing numerous chloroplasts. At the lower end, a group of small brown *rhizoids* furnish the means of attachment to the substratum. The moss plant is *dioecious*, having separate sex organs on different plants. The male gametophytes are shorter than the female gametophytes and bear at the upper tip a cluster of structures known as *antheridia*. Each mature antheridium looks like a tiny club with a wall formed of rather large, thin cells, which forms a receptacle for numerous motile sperm cells. The female gametophyte bears at the apex of the short stem, although in the mature plant

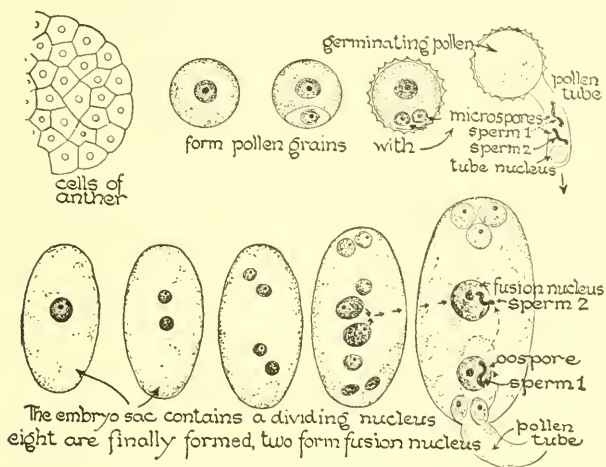
hidden by leaves, a cluster of flask-shaped structures called *archegonia*, at the bottom of each of which is a single rather large egg cell.

Fertilization of the egg can take place only when the antheridia and archegonia are wet from rain or dew. In such an event the sperm cells ooze out in a mucilaginous substance secreted from the walls of the antheridium and pass in drops of water to the necks of the flask-shaped archegonia. Here they are chemically attracted by a substance exuded from the inside of the archegonium and swim down the tubular neck until one meets the egg cell, when fertilization takes place. The gametophytic phase of the moss is the *haploid* stage of the chromosomes, fertilization of the egg restoring the *diploid* number characteristic of the sporophyte. This generation begins with the cell division which follows the fertilization of the egg in the archegonium and results in the growth of a tiny stalk, bearing at its upper end a capsule, that in the adult sporophyte is filled with asexual spores. During the formation of the spores within the capsule, the formative tissues produce a number of large, rounded *spore mother cells*, from each of which by nuclear divisions *tetrads*, or groups of four spores, are formed. During this tetrad formation, a reduction division takes place so that the spores contain only the haploid number of chromosomes.

The moss capsule is quite a complex structure with a cap, or *operculum*, that covers an urn-shaped affair bearing at its upper end a circle of toothlike structures collectively called the *peristome*. As the sporophyte ripens it dries up and the numerous ripe spores are scattered by the action of the peristome teeth, the latter being very *hygroscopic*, or sensitive to moisture. When the weather is humid or wet, the teeth of the peristome curl up and when dry they straighten out, thus expelling the spores, which may then be scattered by the wind. The germinating spore does not grow directly into a leafy plant, but first forms a *protonema* or algalike filament from which upright stalks later arise, while rhizoids grow downwards from it, thus forming again the moss plant. This life cycle with its alternation of gametophytic and sporophytic stages is characteristic of the life cycle of mosses and liverworts, as well as the higher group of the ferns (*Filicinae*).

In the flowering plants (*Angiospermae*), one finds an almost complete suppression of the gametophytic generation, the sex cells or *gametes* being produced in modified leaflike parts of the flower. The floral parts — sepals, petals, stamens, and carpels — are thought of

as leaves which have become metamorphosed from their vegetative form and function to hold the sex structures. The stamens and pistil (carpel) contain spore-forming tissues which, by means of reduction division, produce pollen grains containing microspores (sperms), while ovules produce a female gametophyte and its egg. The sperm cells are formed in the pollen grains, while the egg cells



Development of male and female gametophyte in the flowering plants. Only the cells which actually form these structure are shown. The parts of the sporophyte upon which the gametophyte is parasitic are omitted for the sake of clarity. Read the text carefully and then use the diagrams.

are held within the ovary of the pistil as has been previously stated. In the *angiosperms* or flowering plants the male gametophyte is so much reduced that it consists of only three cells, a tube nucleus and two generative cells (see figure). Just previous to the formation of the pollen grains (male gametophyte) reduction division takes place so that its cells contain the haploid number of chromosomes. The female gametophyte is also greatly reduced. After reduction division, the megaspore divides (see figure) one nucleus migrating to each end of the *embryo sac* (female gametophyte). The nuclei continue to divide until eight are formed in two groups at opposite ends of the embryo sac. From each group a single nucleus then unites with the other to form a fusion nucleus (see figure). At this stage the egg nucleus is ready for fertilization by the sperm nucleus. A double fertilization now takes place, the sperm nucleus fuses with the egg nucleus and the second sperm nucleus unites with the fusion nucleus. The

former gives rise to the young plant, the latter to its food supply, the endosperm. The transfer of pollen in flowers of the same species may result in the fertilization of the egg and subsequent growth of

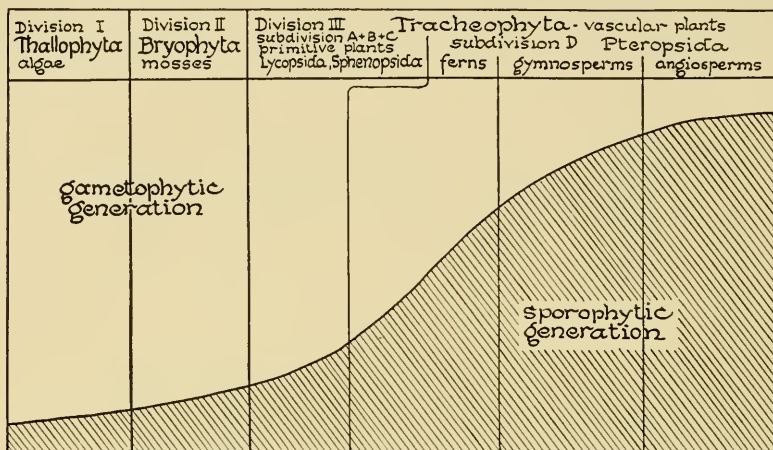


Diagram showing relation of sporophyte and gametophyte generations in the plant kingdom.

the plant body (sporophyte generation). The evolution of sporophytic and gametophytic generations in the plant kingdom is shown in the above chart.

SUGGESTED READINGS

Coulter, J. M., Barnes, C. R., and Cowles, H. C., *A Textbook of Botany*, Vol. I, American Book Co., 1930.

This text gives an excellent foundation for the understanding of sexuality in plants.

Gager, C. S., *General Botany*, P. Blakiston's Son & Co., 1926.

A general botany which gives much information on economic questions, as well as sex development in simple plants.

Robbins, W. J., and Rickett, H. W., *Botany*, D. Van Nostrand Co., 1929. Chs. XV-XXIV.

Excellent diagrams help in the understanding of the development of sex. Sinnott, E. W., *Botany, Principles and Problems*, 3rd ed., McGraw-Hill Book Company, 1935. Chs. XI and XIV-XXIII.

A thoroughly up-to-date treatment of the subject.

Wilson, C. L., and Haber, J. N., *Plant Life*, Henry Holt & Co., 1935.

An interesting and well-written elementary text.

IX

DIVISION OF LABOR IN THE COELENTERATES

PREVIEW. The Hydra, a representative of the phylum Coelenterata; the ectoderm and its functions; the endoderm and its functions; reactions to stimuli; reproduction; regeneration · Hydroids · Suggested readings.

PREVIEW

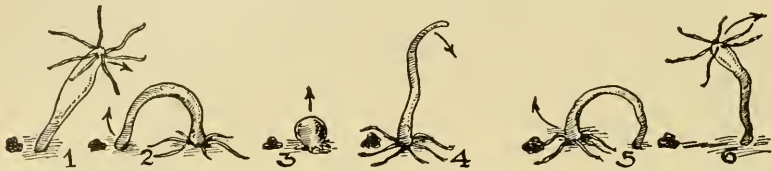
It has already been shown that unicellular animals may exhibit considerable complexity of structure, and that associated with this complexity, there is a separation of functions in different parts of the cell, but we have not traced this division of labor into the many-celled animals or metazoa. The colonial forms, such as *Pandorina*, *Eudorina*, and *Volvox*, claimed by both botanists and zoologists, are interesting examples of aggregations of many cells showing little evidence of organization or division of labor. Even in the colony of *Volvox*, most of the cells have common functions, only the reproductive cells being set off from the others.

The Hydra, a tiny animal little higher in the scale of life, gives every evidence in its structure of being a simple *organism* and not just a collection, or *colony*, of cells. It shows, in a convincing manner, how a simple, many-celled organism lives. It answers the question of how division of labor might arise among the cells of a simple organism. For this reason it is chosen as a *type* in most courses in biology and so has a place in this text.

The Hydra, a Representative of the Phylum Coelenterata

Hydras are quite abundant in many ponds or slow-moving streams, where they may be collected on the stems and leaves of aquatic plants. In an aquarium, they often leave these plants and become attached to the glass walls of the aquarium, where they appear as tiny brown or green cylinders one-half of an inch or more in length. At the free or so-called oral end, a circle of tentacles surrounds a conelike area, the *hypostome*, in which the mouth is found. The opposite, or aboral, end forms a disklike structure which is provided with mucous cells that aid it in sticking to a surface. Hydras are able to move slowly by a looping motion of the body. The green ones, which are much more

active than the brown ones, frequently change their position if food is not abundant. They respond to chemical stimuli of food, to light, and to unfavorable temperatures, food being the chief factor in their environment. The color of green hydras is due to the presence of



Hydra is able to change its position both by turning "handsprings" as shown in the diagram and also by contraction and expansion of the basal portion of the body.

minute green algae, called *Zoochlorellae*, that live in a symbiotic relationship within the endodermal cells.

The term, *Coelenterata*, which is the name of the phylum to which the common *Hydra vulgaris* belongs, comes from the Greek words *koilos*, hollow, and *enteron*, intestine, which may be translated "having an internal digestive cavity," an apt title, since a Hydra is really a hollow, double-walled bag.

The Ectoderm and Its Functions

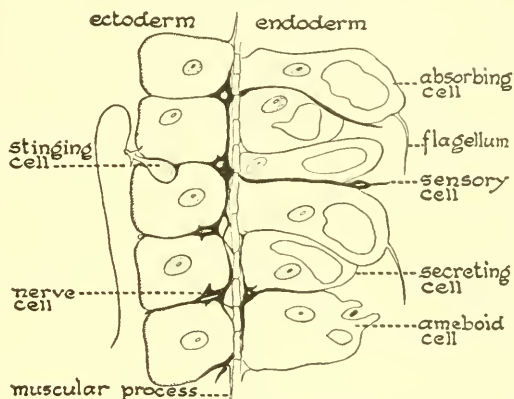
The bulk of the outer layer of cells (ectoderm) is made up of large epithelio-muscular cells, having a layer of muscle fibers placed longitudinally at their bases, that enable the animal to lengthen or shorten its body. A similar layer of fibers on the inner layer of cells which run circularly around the body allows it to expand or contract in diameter. Between the epithelio-muscular cells and near the inner margin of the ectoderm are found numerous smaller interstitial cells from which are derived numerous other cells, including the *cnidoblasts*. Nerve cells are likewise scattered throughout the ectoderm, forming a *nerve net* at the base of the epithelial cells.

Cnidoblasts are most abundant on the tentacles, although they are found on all parts of the body exclusive of the basal disk. They hold four kinds of stinging capsules, *nematocysts*, by means of which the animal paralyzes living prey that comes in contact with its tentacles. The nematocysts are capsules containing a hollow inverted thread which under certain conditions can be thrown out, together with a poisonous substance, *hypnotoxin*, that has the power to paralyze any other small animal which it touches. The nematocyst reacts to cer-

tain chemical stimuli that apparently cause a change of osmotic pressure within the cell, thus forcing out its threadlike portion. After a nematocyst is protruded, the endoblast dies and is soon replaced by another.

The Endoderm and Its Functions

By cutting a section through the body of a Hydra its similarity to a two-walled sac is evident. Between the ectoderm and the inner layer of cells (endoderm) a thin, structureless layer called the *mesoglea* forms as a secretion from the cells of the inner and outer layers. Mesoglea forms much of the bulk of other coelenterates like the jellyfishes. The endoderm consists principally of large vacuolated cells that have flagella at the free or inner end, although they are also capable of developing pseudopodia at this end. Circular contractile fibers are developed at their basal end. Thus



Sections through the body wall of hydra showing the two layers of cells separated by the striated lamella secreted by the basal parts of the ectodermal and endodermal cells.

they are *endothelial-muscular* cells. In the third of the body nearest the basal end, gland cells develop, which secrete digestive enzymes. Nerve and sensory cells are also found in the endoderm.

For a simple animal, the Hydra seems to have many kinds of cells. What is the use of so many? The answer is found in the way it gets food, ingests it, and finally absorbs it into the body cells. By watching a hydra in the aquarium it will be seen that its tentacles are constantly moving as if seeking food. If a tiny bit of raw beef is placed within reach, the animal will bend over and carry the meat to the mouth, the edges of which soon close around it, forcing it inside. If the piece is too large to be taken in, the Hydra actually turns inside out in an attempt, usually successful, to put the meat inside the *gastrovascular cavity*. Once inside the cavity, digestive enzymes from the glandular cells act upon the food, gradually breaking it down into

smaller and smaller fragments. Digestion appears to be aided by the churning movements caused by expansion and contraction of the body wall. Ultimately some of the food is reduced to a soluble state, and absorbed into the endodermal cells. Meanwhile some of the large vacuolated cells put out pseudopodia and engulf some of the undigested food particles, finishing the digestive process inside their own cell-bodies. Thus Hydra has two types of digestion, one intracellular, like that found in all unicellular animals and, therefore, more primitive; the other, extracellular, that is, taking place in the digestive cavity. Most of the food of the Hydra is digested in the latter way, the cells lining the cavity absorbing the digested food before passing it along to the cells of the ectoderm. According to Hegner, part of the absorbed food is in the form of oil globules which are passed over to the cells of the ectoderm and stored there for future use. Unusable or undigested material is thrown out of the digestive cavity by a sudden contraction, there being no other way of eliminating such wastes except through the surface of the body, as in lower forms. Hydra like other animals uses oxygen to release energy. Respiration probably takes place through the surface of the entire body, the cells receiving oxygen and giving off carbon dioxide by diffusion through the cell membranes.

Reactions to Stimuli

Hydra show very definite reactions to certain stimuli, most of which have to do with obtaining food. Hungry Hydra are much more active than well-fed ones, and respond to various chemical stimuli besides reacting to mechanical stimuli, to heat, to light, and to electricity, all of which indicates the possession of some sort of simple nervous system, since the movements made are more or less co-ordinated. If touched lightly on a tentacle with a needle, only the tentacle contracts, but with increased stimulation, the other tentacles contract, until finally, the whole animal draws down into a little ball. Its physiological condition, according to Jennings,¹ determines whether it "shall creep upward to the surface and toward the light, or sink to the bottom; how it shall react to chemicals and to solid objects; whether it shall remain quiet in a certain position, or reverse this position and undertake a laborious tour of exploration."

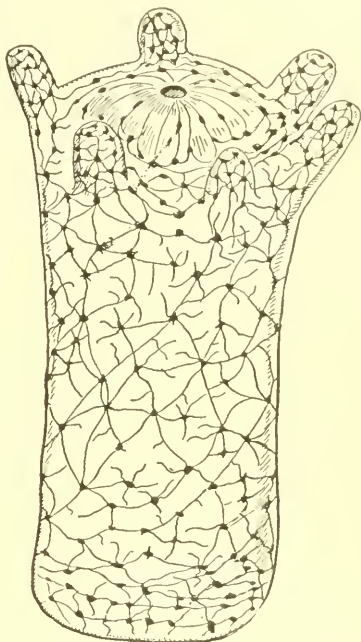
The nervous system of Hydra forms a nerve net. It consists of a concentration of primitive nerve cells about the base of the hypostome

¹ Jennings, *Behavior of the Lower Organisms*. Columbia Univ. Press, 1915, p. 231.

and the foot. This network of cells lies in the ectodermal layer of the animal, and receives impulses from sensory cells as well as transmitting them to the muscle fibrils. The sensory cells of the ectoderm vary in their location; one type occurs on the tentacles, one on the hypostome, and a third on the foot (base). Neuro-sensory cells which are located in the mid-body area also resemble nerve cells, except that they send processes to muscle fibrils and so become intermediate between those receiving stimulation and those making the response. Some nerve cells appear in the endodermal layer but are not, so far as can be determined, connected with the ectodermal nerve net.

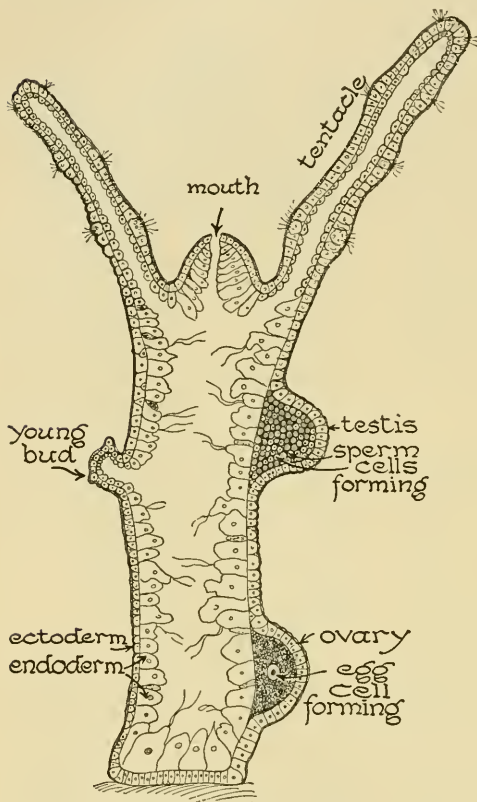
Reproduction

Probably the most important function of the interstitial cells is their growth into sex cells. Most Hydras are hermaphroditic, that is, have both kinds of sex cells present in the same individual, but since the sperm cells and ova ripen at different times, fertilization is accomplished by sex cells from different individuals. Sperm cells are produced by the mitotic division of interstitial cells, each of which first produces a number of parent male cells, containing the somatic number of chromosomes. These cells divide four times and in the process a reduction division takes place, leaving the sperm cells with just half as many chromosomes as the body cells. A somewhat similar process takes place in the formation of the ova. One interstitial cell becomes larger than the others, rounds into a sphere, and is surrounded by other interstitial cells, which serve as an ovary for the growing egg. The latter continues to grow in size, forming yolk from the surrounding cells. Just before the egg becomes mature, the process of *maturation* takes place (see page 429), dur-



The nerve net in a young hydra as seen with an intravital methylene-blue stain. Note the ringlike arrangement in hypostome and foot. What effect might such an arrangement have on movement? (After J. Hodzi.)

ing which the number of chromosomes is reduced to half the body number. Spermaries and ovaries can be seen in the living *Hydra* as little lumps on the ectoderm. The spermaries are always found near



Longitudinal section through the body of a *Hydra*, showing both sexual and asexual reproductive structures.

the free end of the body, the ovaries, when present, being nearer the base. The egg is fertilized while still attached to the parent and develops into an embryo surrounded by a protective chitinous case, in which stage it sinks to the bottom of the pond for a resting period before emerging as an adult.

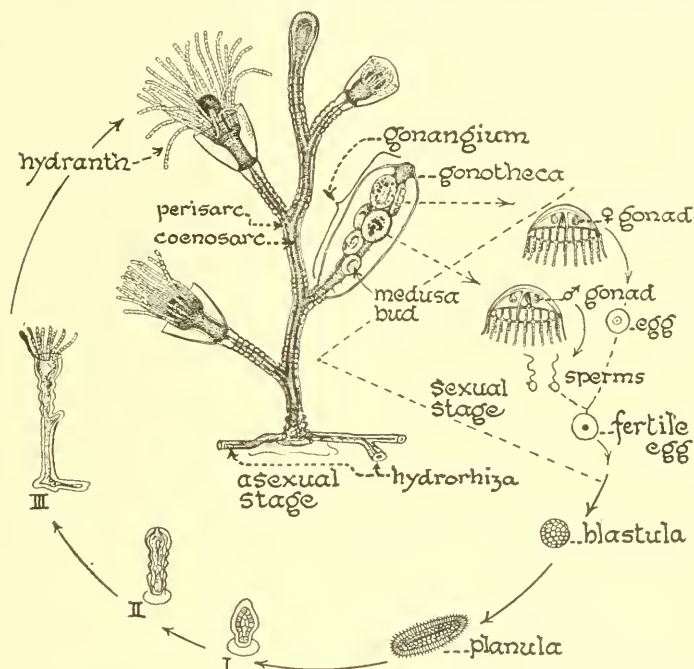
Asexual development also takes place. A small bulging area, formed by the interstitial cells, appears on the side of the body, which more or less rapidly grows into a short column surrounded by tentacles, depending on the food supply available for the parent *Hydra*. When fully developed the bud may separate from the parent and lead a separate existence. A *Hydra* frequently produces more than one bud on a single animal.

Regeneration

Although regeneration takes place in other groups of animals it is best seen in the phylum, Coelenterata. The primitiveness of *Hydra* is shown by the fact that it can regenerate or replace lost parts by growth of the body cells. It may be cut lengthwise or crosswise, or even into small pieces, and the fragments will, under favorable conditions, give rise to complete individuals.

Hydroids

Hydra vulgaris is a fresh water form, but many more representatives of the Coelenterate group are found in salt water, the most familiar being the hydroids found attached to the piles of wharfs and other submerged objects. Among the most common hydroids are members



Life cycle of *Obelia* — showing alternation of generations! Compare with text pages 135–136 for explanation of diagram.

of the genus *Obelia*. These animals form colonies, in which the individuals, called *polyps*, or *zooids*, are attached to each other by means of hollow stalks, covered with a chitinous, cellophanelike *perisarc*. At the tip of each branch, the covering expands into a cuplike *hydrotheca*, which surrounds the living polyp. As in *Hydra*, each individual polyp of *Obelia* is hollow and two layered, with a circle of tentacles about the raised hypostome, in which the mouth is located. The tentacles are provided with nematocysts that act in the same manner as in the *Hydra*. The food cavity, however, extends down each stalk-like branch or individual and is continuous with that of the other polyps, thus forming a common gastrovascular cavity in which food

is digested. There are also cells, as in *Hydra*, which perform intracellular digestion.

Obelia gives rise to another type of polyp than the nutritive individual just described. This is the *reproductive polyp*, or *gonangium* that grows out as a bud, expands into a knoblike central axis known as the *blastostyle* within a chitinous, closed vase, called the *gonotheca*. On the sides of the blastostyle budlike structures, called *medusa buds*, develop. These break off and swim away as tiny bisexual jellyfish, or *medusae*, representing the *sexual* stage in the life history. A sperm cell from one of these medusae fertilizes an egg from another, which, after a developmental period, becomes a free-swimming ciliated larva, called a *planula*. After a short time the planula settles down and produces a new asexual colony of *Obelia*. Other related forms as the jellyfish, *Aurelia*, possess a predominating free-swimming stage, while the sessile, non-sexual generation is reduced.

This life cycle is reminiscent of a similar condition in plants, which also have an *alternation of generations*. During the maturation of the sperm and egg cells, reduction division takes place in which the chromosomes of the sex cells are reduced to half the body number. In alternation of generations of plants, all the cells of the gametophytic generation are haploid, but as in animals only the mature sex cells are haploid, the body cells having the same number of chromosomes as the body cells of the sexual generation. The end result accomplished in both plants and animals is the same.

SUGGESTED READINGS

- Curtis, W. C., and Guthrie, M. J., *Textbook of General Zoology*, 2nd ed., John Wiley & Sons, Inc., 1933, pp. 278-301.
 Guyer, M. F., *Animal Biology*, Harper & Bros., 1931, pp. 197-206.
 Hegner, R. W., *College Zoology*, The Macmillan Co., 1936. Ch. X.
 An authentic description of *Hydra* and its activities.

X

BEING A WORM

PREVIEW. A typical worm; external structure of the earthworm (*Lumbricus terrestris*); the digestive tract and its functions; how blood circulates, the blood and its functions; organs of excretion; the muscles and their work; reactions to stimuli; the nervous system and its functions; the reproductive system and reproduction · Regeneration · Suggested readings.

PREVIEW

Passing from the simple two-layered development of the Hydra, in which division of labor among the cells is slight, we come to the earthworm, another lowly animal, but one which represents the big idea of a typical three-layered, segmented form.

In Hydra, the egg develops into an adult form having two layers, namely, *ectoderm* and *endoderm*, but in the earthworm, a third layer, the *mesoderm*, appears, which is characteristic of all the higher animals. These three germ layers are of great significance in the study of animals, for all of the complex tissues of the body are derived from them.

Another reason why the earthworm is chosen for study is because it represents a very simple type of segmented or metameric animal of which a great variety is found not only among worms but also among insects and crustaceans. Judging by the insects, segmented animals are the most abundant and successful of all animals, since they outnumber all other species. The pages that follow will concern themselves chiefly with the "hows and whys" of the activity of the common "night crawler," some of which are: How far has division of labor progressed? What organ systems are well developed? How does co-ordinated movement take place, and how do worms become aware of their surroundings?

A Typical Worm

External Structure of the Earthworm (Lumbricus terrestris)

The body of the earthworm is divided into segmented parts, or *metameres*, which in adult worms may number over one hundred. The body tapers bluntly at each end, the anterior end being easily

distinguished by the rounded mouth which is just ventral to or under a small protuberance, the *prostomium*, while the *anus*, or posterior end of the digestive tract, is a tiny slit in the last segment. The posterior end is also flattened, and between segments 32 to 37, not counting the prostomium enclosing the mouth as the first, there is found a swollen region, called the *clitellum*, important in reproduction.

The upper or dorsal side may be distinguished by its darker color, while the ventral side is slightly flattened and contains four double rows of tiny projections called *setae*, which give the worm a grip on the ground when in locomotion. The dorsal side is devoid of any



Wright Pierce

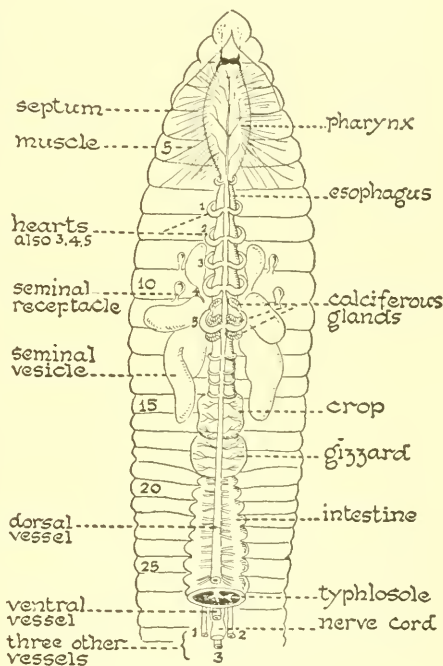
The common earthworm, *Lumbricus terrestris*. Note the swollen area, or *clitellum*.

openings except some very minute *dorsal pores* that communicate with the body cavity, or *coelom*, but the ventral side has several paired openings, difficult to find, which lead to the reproductive and excretory organs. The surface of the body is covered with a delicate iridescent cuticle, secreted by the living epithelial cells of the skin, but which is itself dead. Its iridescence is caused by the presence of numerous grooves (*striae*), and its surface is pierced with small holes, which are openings for the mucous gland cells of the skin. The coelom or body cavity is cut up into small compartments by partition walls, or *septa*, that are absent or incomplete in the extreme anterior region, between the 18th and 19th segments, and in the region posterior to the reproductive organs. The coelom in the living worm is filled

with fluid which passes from one segment to another through single perforations in each of the septa. The fluid contains amoeboid cells, that probably serve as scavengers, and it acts as blood, bathing and nourishing the tissues and carrying away wastes.

The Digestive Tract and Its Functions

The food of earthworms, bits of animal or vegetable matter mixed with soil, is taken into the mouth by means of suction. A muscular *pharynx*, previously moistened by the fluid poured out from small glands in its wall, is able to pull the material into the *esophagus*, a thin-walled part of the tube which extends from the 6th to the 15th segment, beside whose walls, between segments 10 to 12, there are embedded three pairs of whitish structures, the *calciferous glands*. These glands produce a limy secretion supposed to neutralize the food materials. The esophagus leads into a thin-walled *crop*, occupying the 15th and 16th segments, which opens into a thick-walled, muscular *gizzard* extending over segments 17 and 18. The latter organ has an internal chitinous wall, and is probably used to macerate bits of undigested food by means of muscular contraction. The remainder of the food tube, extending from the 19th segment to the anus, is called the *intestine*. Its inner surface is increased by a fold on the dorsal side (*typhlosole*), while surrounding it there is a layer of yellow-brown tissue *chlorogogen cells*, which are thought to aid in excretion and possibly digestion of food. The wall of the intestine contains gland cells that secrete at least three kinds of enzymes, which digest starches, fats, and proteins. The digested food is absorbed

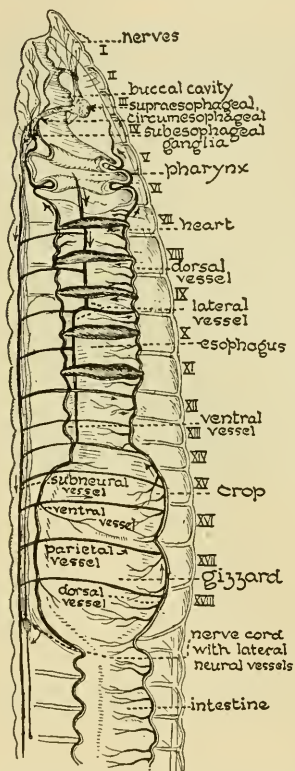


The earthworm (*Lumbricus terrestris*) opened from dorsal side to show internal structure. (After Sedgwick and Wilson.)

through the walls of the intestine, most of it passing into the blood and directly into the coelomic fluid, where it may continue to the muscular wall outside the coelom. Unusable material, mostly earth, is passed off by muscular contraction through the anus, and may often be seen on lawns as little piles of "castings."

How Blood Circulates

Since in the earthworms there is a very different arrangement than in *Hydra*, where food is directly available to all the cells, we would expect to find some means of distributing it to the tissues where it

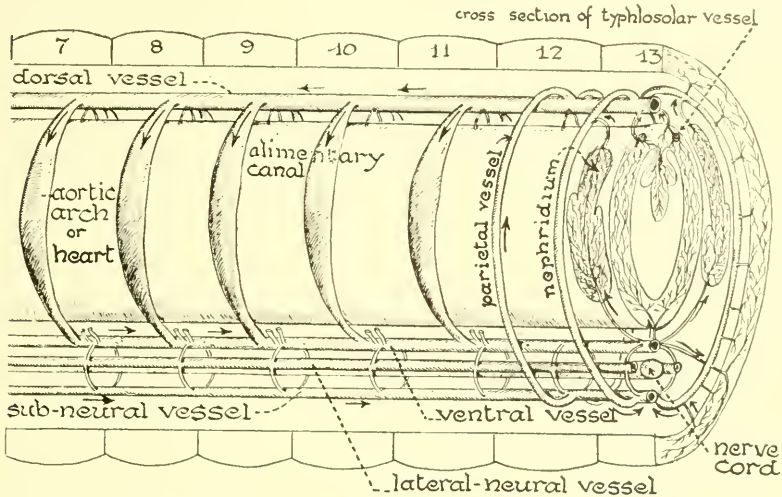


The circulatory system of the earthworm.

may be used. This is accomplished by means of a closed system of blood vessels. Some idea of the circulation may be derived by a study of the accompanying diagrams. Five large blood vessels run lengthwise through the body, one *dorsal vessel*, close to the food tube, into the walls of which it sends two pairs of lateral vessels in each segment; another, the *ventral vessel*, runs just ventral to the digestive tract and also sends lateral branches into its wall. There are also three others, the paired *lateral neural vessels* and the *subneural vessel*, which run longitudinally, the latter directly under the nerve cord, and two other smaller ones lying parallel one on each side and above the nerve cord. Five "hearts," so called because of their frequent contractions, encircle the esophagus in the region of the 7th to the 11th segments, connecting the dorsal with the ventral vessel. Blood passes into the dorsal vessel especially from a long *typhlosolar vessel* which helps drain absorbed foods from the intestinal walls, flowing forward until it reaches the "hearts." Its forward movement is caused by slow, regular contractions of the dorsal

blood vessel. The blood passes posteriorly through the "hearts" and then flows into the ventral blood vessel. Here it passes posteriorly, although some of it moves from the hearts toward the

anterior end of the body. Blood also passes through two *intestino-integumentary vessels* which pass off at the 10th segment to supply the walls of the esophagus and the skin, and to nephridia of that region. *Parietal vessels* connect the dorsal and subneural vessels,



The "hearts" of the earthworm. How do they function in circulation?

that branch from the ventral vessel to supply the body muscle walls and nephridia. Blood also passes from the ventral vessel to the body walls, and to nephridia, and returns to flow, after passing through capillaries, into the lateral neural trunks. In the subneural vessel, the blood flows posteriorly and thence up by way of the parietal vessels into the dorsal vessel. Both dorsal and ventral vessels supply the anterior part of the worm.

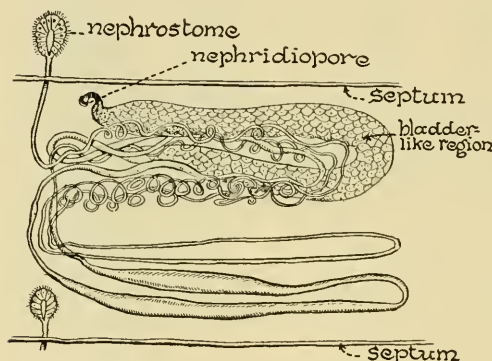
The Blood and Its Functions

The blood of the earthworm consists of a liquid plasma, carrying colorless corpuscles which are flattened spindle-shaped bodies. The red color is due to hemoglobin, the same oxygen-carrying substance found in the blood of man. But in the earthworm the plasma is colored rather than the corpuscles. The exchange of food and oxygen, which the blood picks up in the intestine and body walls, respectively, occurs in the tiny lymph spaces around the individual cells. Respiration takes place through the moist outer membrane

of the skin, where the oxygen is picked up and combined with the hemoglobin, to be later released in the cells of the body where work is done. Carbon dioxide and wastes are here taken up by the blood and carried back to the skin and to the *nephridia* or excretory organs. One can easily demonstrate the network of tiny capillaries in the skin where this exchange takes place.

Organs of Excretion

The paired nephridia are essentially coiled tubular organs, made up of a ciliated funnel or *nephrostome* that opens into the coelom, a thin ciliated glandular tube, that loops on itself about three times, and a pore, the *nephridiopore*,



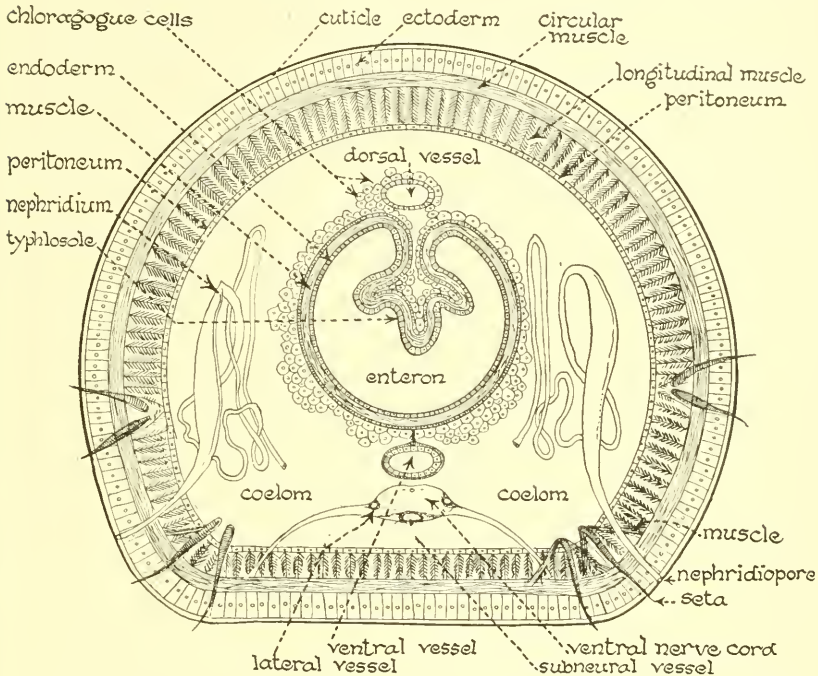
A nephridium of an earthworm. Trace the passage of fluid from the coelom to the exterior of the worm. Note the ciliated surface of the nephrostome. What is its function? (After Wolcott.)

the surface of the glandular tubules. One characteristic feature of the nephridium is that it always passes through the septum separating two segments.

The Muscles and Their Work

Movement is brought about by muscular contraction. As an earthworm crawls, a wave of contraction from the posterior toward the anterior appears to move up the body of the worm. A careful examination shows that movement is brought about by the contraction and relaxation of two opposing groups of muscle fibers and by the movement of the rows of setae on the ventral surface. The muscles are arranged in two layers just under the skin, an outer circular layer running around the body and an inner longitudinal layer. When the worm lengthens, the longitudinal muscles relax

and the circular muscles contract, while a shortening of the worm results from a contraction of the longitudinal muscles and a relaxing of the circular muscles. Each stiff seta is placed in a little sac, from which it extends out beyond the surface of the body. Inside the sac, attached to the seta and to the outer body wall, are two pairs



Cross section through earthworm. Compare this with cross section of *Hydra*. What advances in complexity of structure do you find? In the earthworm the most noticeable difference is seen in the coelom, which is formed by a splitting of the mesodermal bands in the embryo (seen on page 197). Note that the coelom is completely lined by a delicate membrane, the peritoneum. Notice also the longitudinal fold or typhlosole which gives more surface to the inner wall of the intestine. What is its function? In the diagram, the funnels of the nephridia are not shown. Explain why this is so.

of muscles by means of which the seta can be directed forwards or backwards, depending on the direction the worm is traveling. When the worm is moving forward, the anterior end is extended, the setae, that are pointed backward, are set into the ground, serving as anchors, while the posterior end of the worm is pulled forward by means of the contraction of the longitudinal muscles.

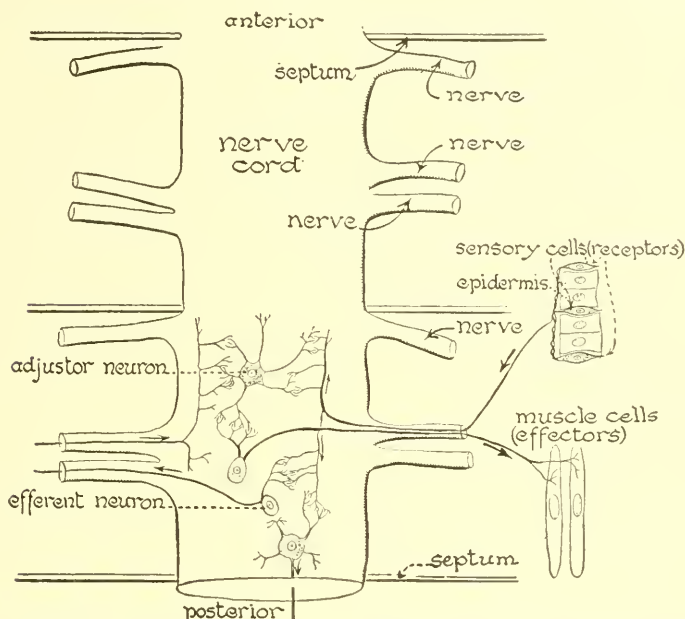
Reactions to Stimuli

Earthworms live in soil and make burrows which extend from a few inches to several feet under ground. They are nocturnal and lie in their burrows not far from the surface during the day time, coming out at night to forage for food. In winter, they go below the frost line, remaining there inactive. In hot and dry weather, they go as far down as possible into the earth, while a heavy rain will bring them out of their burrows in great numbers. Earthworms react positively to mechanical stimuli. A vibration on the earth will send them down into their burrows. They are positively attracted to surfaces of solid objects, as can be seen if worms are placed on moist blotting paper in a covered pan. They will soon be found lying along the edges of the pan, where *two* surfaces are in contact with the body. This response to contact apparently keeps them quite constantly in their burrows. They react positively to certain chemical substances, like foods, and move away from others. A match that has been dipped in ammonia and placed near the anterior end of an earthworm will demonstrate this reaction. They respond positively to moderate moisture, which is needed for respiration through the body covering, and to different intensities of light, by withdrawing from bright areas and moving toward weak illuminations. Like Hydra, however, reactions to stimuli depend largely on the "physiological condition" of the worm, that is, upon internal rather than upon external factors.

The Nervous System and Its Functions

The earthworm has a simple type of *central nervous system* consisting of a ventral nerve cord, with thickenings, called *ganglia*, in each segment, a dorsal "brain" or *supraesophageal ganglion*, made up of two ganglia, and a "ring" of nervous tissue, called the *circum-esophageal connectives*, which extends around the esophagus, connecting the "brain" with the ventral nerve cord. Lateral nerves, which leave the "brain" and cord to end in muscles, skin, and other organs, form a *peripheral nervous system*. The worm does not have visible organs of sensation, but the skin, especially at the anterior and posterior ends, is dotted with groups of tiny sensory cells. Some of these are sensitive to light, and still others probably to odor. Stimuli received by these cells are transmitted to the central nervous system by means of nerve fibers. Those which lead from the sensory cells to the central nervous system are known as *afferent* fibers, while out-

going fibers which originate in nerve cells within the cord are known as *efferent* or motor fibers, since they end in muscle cells and stimulate them to contract, thus causing motion. The unit over which these impulses travel is called a *neuron*, which is the term given to the nerve cell and its prolongations. (See page 340.) In the earthworm sensory



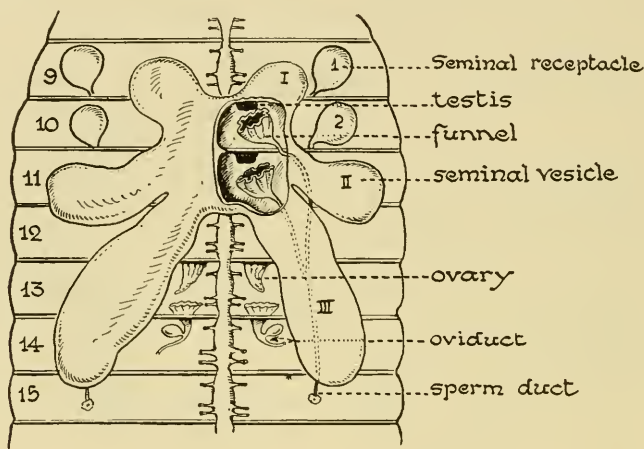
The nerve cord of the earthworm showing neurons concerned in the reflex arc. Explain how adjustment to an unfavorable condition might be affected. How might movement in another segment of the worm be co-ordinated with the one shown in the diagram? (After Curtis and Guthrie.)

impulses are passed longitudinally, both anteriorly and posteriorly, by means of the peripheral nervous system, and these impulses are modified by means of *adjustor neurons* in the central nervous system. This accounts for the co-ordination between segments as the worm crawls toward a desirable object or suddenly withdraws from a harmful situation.

The Reproductive System and Reproduction

Earthworms have both *testes* and *ovaries* in the same animal, and are therefore *hermaphroditic*, but they are not capable of self-fertilization. Two pairs of testes lie attached to the anterior walls of

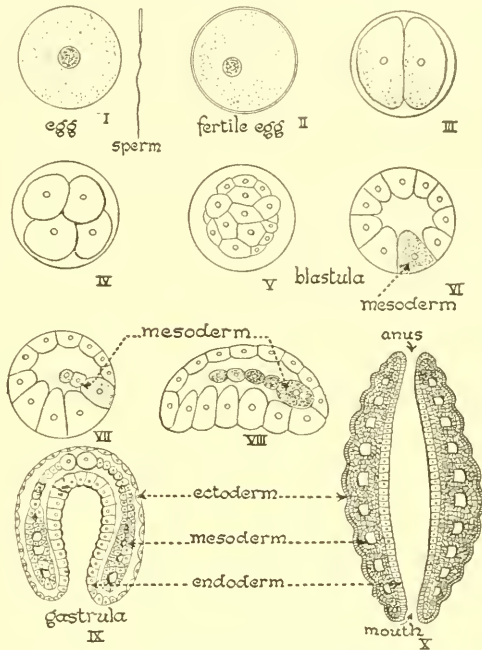
segments 10 and 11, and are enclosed by the ventral unpouched portion of two of the three *seminal vesicles*. Dorsally the three pairs of large pouches of the seminal vesicles in segments 9, 11, and 12 are light-colored structures easily seen in a dissection. Immature sperm cells are passed from the testes to complete their development in the seminal vesicles. Two pairs of *vasa efferentia* in somites 10 and 11 fuse to form the paired *vas deferens* that carry the sperm to the exterior through the male openings on segment 15. A pair of tiny ovaries are attached to the anterior septum of segment 13, the eggs



Reproductive organs of the earthworm. The seminal vesicles are cut away on one side to show the funnels of the sperm ducts. Read your text carefully and explain how reproduction takes place.

passing from this into the *oviducts* which open to the surface on segment 14. Fertilization of the eggs is accomplished by the process of *copulation* in which two worms, placing themselves in opposite directions, become "glued" together on their ventral surfaces by means of mucus secreted from the glands of the clitellum region. While they are thus placed a mutual transfer of sperm cells from the seminal vesicles of one worm to the *seminal receptacles* of the other takes place, rhythmic muscular contractions of the body helping to force the sperms along. Then the worms separate. Later, when the eggs are to be laid, a cocoonlike band of mucus is formed by the clitellum, which is forced forward by movements of the worm, and as it passes by the oviducal pores, receives the ripe eggs. When it passes over the opening of the seminal receptacles on the ventral surface of

segments 9 and 10, it receives sperm cells from the other worm that have been stored there. The girdle is passed down over the anterior end of the worm, slipped off, forming a closed case which contains the eggs, sperms, and a nutritive fluid. These capsules may be found in late spring under stones, boards, logs, or in manure heaps. After fertilization, the egg of the earthworm divides first into two, then four, then eight cells, and so on, continuing until a hollow ball of cells, called a *blastula*, is formed. These cells are not all the same size, larger cells appearing on the lower pole of the sphere, which begins to flatten and show a depression, forming eventually a hollow cuplike affair, called the *gastrula*. This process known as *gastrulation* places the larger cells of the lower pole on the inside of the cup where they become the endoderm, leaving the outer cells of the sphere to form the ectoderm. Meantime a third layer of cells which lies between the other two layers buds off and becomes the mesoderm. This latter layer gives rise to the musculature, blood vessels, and most of the excretory and reproductive tissues; the endoderm forms the food tube and much of the glandular material connected with it; the ectoderm gives rise to the epiderms, the nervous system and sense organs, and the outer portions of the nephridia, reproductive ducts, and digestive tracts. The young worms remain in the egg case until they are about an inch in length. When first hatched they have no clitellum, since this organ appears only in mature worms.



Stages in development of earthworm. Figures II-V. Segmentation of egg and formation of blastula. Figures VI-VIII. Sections, showing formation of mesoderm as a band of cells. IX. Late stage of gastrula, showing coelomic spaces in mesoderm bands. X. Longitudinal section of young worm showing food tube, mouth and anus. (After Sedgwick and Wilson.)

Regeneration

Earthworms, like other members of the lower phyla of the animal kingdom, have the ability, under certain conditions, to grow new parts. Experiments have been made by Hazen, Morgan, and others that show if a sufficient number of segments are present a worm may regenerate a new posterior end, or even a new anterior end. Earthworms have even been successfully grafted end to end.

SUGGESTED READINGS

Curtis, W. C., and Guthrie, M. T., *Textbook of General Zoology*, 2nd ed., John Wiley & Sons, Inc., 1933.

Excellent chapter on the Annulata, pp. 350 to 375.

Darwin, Ch., *Formation of Vegetable Mould*, D. Appleton & Co.

An easily read classic which ought to be known to every student of biology.

Hegner, R. W., *College Zoology*, 4th ed., The Macmillan Co., 1936.

Chapter XV is a well-written and authentic chapter on the Annulata.

XI

THE POPULAR INSECT PLAN

PREVIEW. The insect body plan; the head and its appendages; the thorax and its appendages; honey manufacture; digestion; circulation, respiration, and excretion; the nervous system · Reproduction and life history · The life in the hive · Suggested readings.

PREVIEW

It would seem right in a text on biology that a representative of the largest and most successful group of animals should be described and that more than a passing glance be given to this enormous group, which contains far more than half of all living animals. We are always meeting insects, because they are so plentiful rather than from choice. They annoy us when we are in the woods, they bite us when we are lolling on the beach at the seashore, they get into our foods and render them unfit for use, or they eat our stored clothes. Worse than this, they defoliate trees, and sometimes destroy forests, and take their tithe of the nation's food crops. A good many have been implicated in the transfer of disease and some have actually rendered regions uninhabitable by man.

Biologists have a good reason for a study of representatives of the great phylum, Arthropoda, because the arthropod plan of structure is the one employed by the majority of the species of the animal kingdom. In its simplest form, it represents an organism made up of segments, each body segment bearing a pair of jointed appendages. The head always bears at least one pair of jointed *antennae* or feelers, jointed mouth parts, and usually *compound eyes*. The body is protected by an exoskeleton composed of chitin secreted by the cells beneath. A digestive tract passes straight through the body and there is a nervous system such as we saw in the Annelids, consisting of a ventral nerve cord, a dorsal "brain," and a nerve ring about the esophagus. Dorsal to the food tube is an elongated heart, there being no closed system of blood vessels. Such a simple arthropod would be difficult to find for laboratory purposes, so we have to use other more specialized forms.

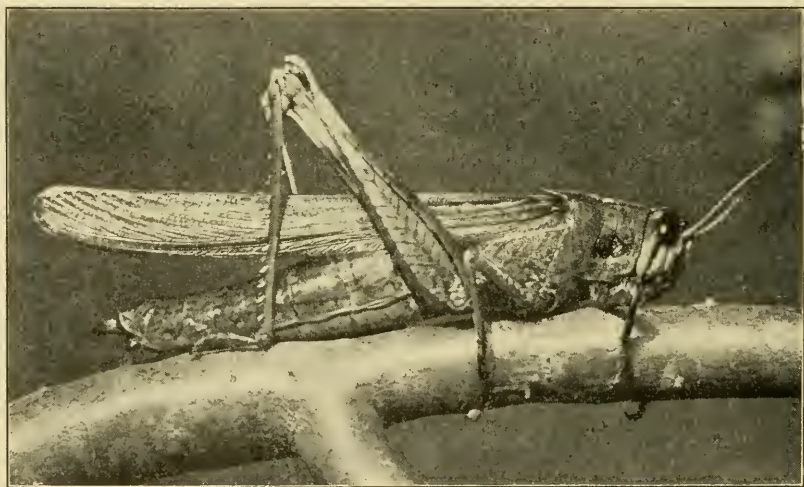
From the strictly biological point of view there is another reason for the study of an insect. It offers an example of a segmented ani-

mal that has gone in for specialization in a big way. The insects are a subdivision of the Arthropods, animals that have jointed legs and jointed bodies, and as such show definite repetition of similar parts, or *metamerism*, a phenomenon previously noted in the Annelids. As a group they have become differentiated to such an extent from their not so distant relatives that, like the man on the flying trapeze, they "fly through the air with the greatest of ease." In no other group except the birds has this ability been so exploited. In addition some forms, such as the bees, ants, and wasps, show an astonishingly complex social life.

As a successful group insects show numerous adaptations, not only in structure but in life habits. They are not only active but often so inconspicuous as to pass unnoticed by their enemies. Insects are characterized by a rapidly growing larval period associated with an abundance of food. The protected pupa is characterized by internal changes fitting the organism for the active reproductive life of an adult. They deserve our careful consideration as a type for study.

The Insect Body Plan

Adult insects are readily identified because the body is made up of three parts, an anterior *head*, a mid region or *thorax*, and a posterior region, the *abdomen*. The body may be further subdivided into

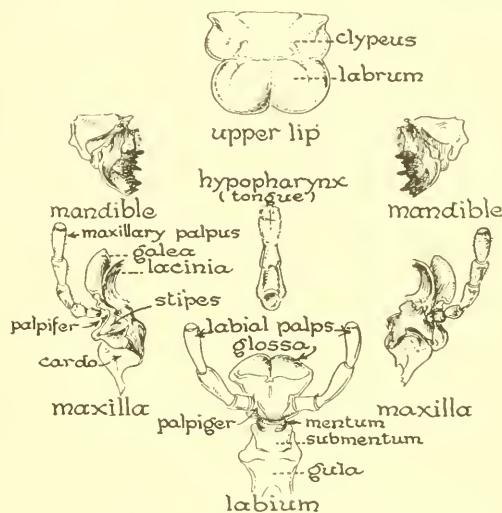


Wright Pierce

The large vagrant grasshopper (*Schistocerca gregaria* Scudder) normal size. A typical insect. Give all the distinguishing marks of an insect as shown in this photograph.

segments and has three pairs of jointed thoracic legs. These characters distinguish any insect. If you will refer to the "Roll Call" you will see that the various orders of insects are distinguished by still other characters, such as the presence or absence of different kinds of wings, or differences in the structure of the mouth parts, which may be modified for various purposes. All insects breathe through *tracheal tubes* and have a body armor of *chitin*, a protein substance something like cow's horn.

Many zoologists like to use a locust or "grass-hopper" as a laboratory type for study. This is because the body parts are easy to see and because it is a form having relatively simple mouth parts. It is provided with two pairs of jaws, a forklike pair, the *maxillae*, and a pair of hard toothed jaws, the *mandibles*. These parts when

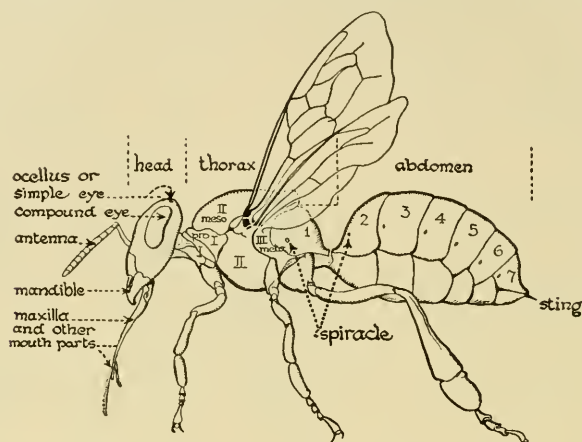


Mouth parts of the locust.

not in use are covered by two flaps, the upper and lower lips (*labrum* and *labium*). Such mouth parts are found in the bee, although somewhat modified from the more primitive type seen here. Moreover, the locust is a more typical insect because it has three distinct thoracic segments, known as the *pro-*, *meso-*, and *metathorax*, and it also has a more nearly typical number of abdominal segments, which in most insects is ten or eleven. The bee, although not such a typical insect, shows so many adaptations, and in addition has so complex a social life, that it is selected as a representative of the class *Insecta*.

The honey bee (*Apis mellifica*) forms colonies which include three kinds of individuals; first, *workers*, bees with undeveloped female sex organs, which form by far the largest number in the colony; second, *drones*, or males; and third, a *queen*, or fertile female. An average-sized colony of bees may contain from 35,000 to 50,000 workers, several hundred drones, and one adult queen. In the following description the worker bee is used, unless otherwise specified.

A study of the accompanying illustration indicates that the bee, like other insects, has three body divisions — head, thorax, and abdomen, but instead of the usual three thoracic parts, there are four, since one segment from the abdomen becomes fused with the thorax,

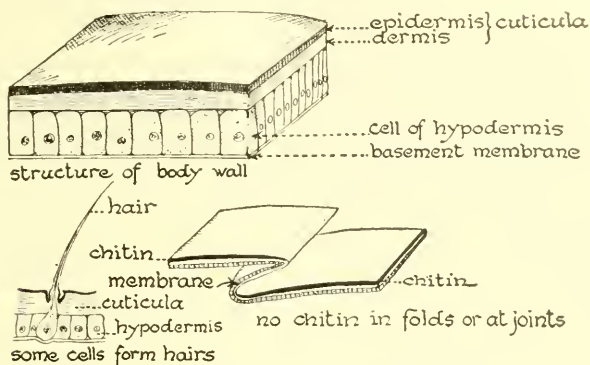


Worker bee, lateral view, hairs removed, showing parts of body and appendages on left side. (After Snodgrass.)

leaving only six visible segments in the abdomen. The head bears a pair of jointed antennae, or "feelers," large compound eyes, and mouth parts much modified from the plan shown by the locust. Three pairs of jointed legs and two pairs of membranous wings are attached to the thorax, the wings growing out of the meso- and meta-thorax. At the posterior end of the abdomen an *ovipositor* in the female is modified in the worker into a *sting*, which is withdrawn inside its sheath within the body when not in use. The body is covered with a horny three-layered coat made up of an outer chitinous *cuticula* that covers the entire body except at the joints, where it becomes membranous, thus allowing movement; a middle layer of cells called the *hypodermis*; and an inner delicate *basement membrane*.

Protruding from the chitinous covering are many hairs and bristles, outgrowths formed by the hypodermis, in which there are several kinds of cells, some forming the chitinous coat, others the hairs, and still others *gland* or *sensory* cells. In some cases the hairs are hollow and contain sensory nerve endings. We must picture these animals covered with heavy armor, through which sensation is impossible

except where sensory nerve endings penetrate the armored surface, ending in various sense organs such as compound eyes, antennae, and sensory hairs.



The body wall and its modifications. The epidermal portion of the body wall is composed of a horny substance called chitin, the dermal portion having a somewhat different chemical nature, like cellulose. In places where movement is necessary the chitin is replaced by a flexible membrane. Several types of hairs are found, some solid, others hollow, all outgrowths of the exoskeleton. (After Snodgrass.)

The Head and Its Appendages

According to the observations of embryologists the head of the bee is made up of six segments that are fused together in the adult. This statement is based on the well-established fact that every segment in its embryonic condition bears a pair of appendages. Two compound eyes, which are very large in the drones, are placed on each side of the head, while between them in a triangle on the top and front of the head are three simple eyes, or *ocelli*. Below and between the compound eyes are the jointed antennae. The mouth parts consist of *labrum* and *labium*, the latter a complicated structure which contains the long, flexible *ligula* or tongue with a spoonlike *labellum* used by the bee in withdrawing nectar from flowers. Attached to each side of the ligula are two jointed *labial palps*. The base of the labium consists of two pieces, the *submentum* and *mentum*. The upper jaws or *mandibles* are on each side of the labrum, while the lower jaws or *maxillae*, with their tiny palps, fit closely and laterally over the mentum. The liquid food, *nectar*, is first collected by means of the hairs on the ligula, the maxillae and labial palps being formed into a tube through which the ligula works up and down with a kind of pumping

motion although the entire labium aids in the process. While feeding, the flap of the labrum or *epipharynx* is lowered, making a passageway for the nectar to pass into the mouth. Thus the mouth parts, which are all present in the locust as separate structures,

here form a sort of *proboscis*, that when not in use is folded back underneath the head.

Bees also feed on solids such as pollen and "bee sugar," which they moisten with regurgitated honey and saliva before swallowing. The mandibles and maxillae are both used in feeding on solids, but the chief uses of the mandibles are in building honeycomb.

Bees are well provided with sensory structures. Experiments by McIndoo and Von Frisch indicate that bees can distinguish between different-tasting substances, for some of which they show strong preferences. But whether they can actually taste or

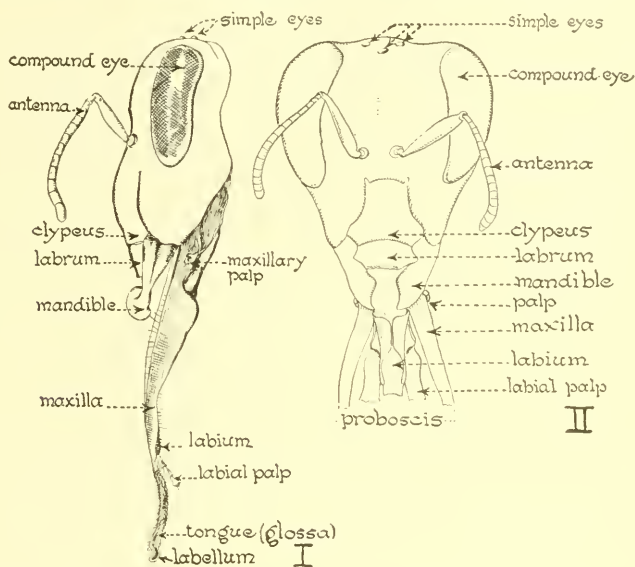


Wright Pierce

Head of worker bee. Anterior view. Compare this with the accompanying line drawing and identify as many structures as you can.

whether they distinguish substances by means of a sense of smell is difficult to prove. Several experiments have been made that prove the presence of a well-developed perception of odor. Among the most convincing experiments were those in which Von Frisch trained bees to select certain odors, such as oil of orange peel, out of 43 other odors. He concludes that not only can bees discover feeding places through a sense of smell but they tell other bees of the existence of food supplies by means of a "round dance" in which the successful bee probably holds the odor of the particular flowers on which she has been feeding and disseminates it to the bees that crowd around her in the hive.

Experiments in which the antennae were removed, together with evidence from microscopic examinations of the antennae, indicate that they hold many of the sense organs which perceive odors. Small pits, in which these sensory cells are located, are found on the surface

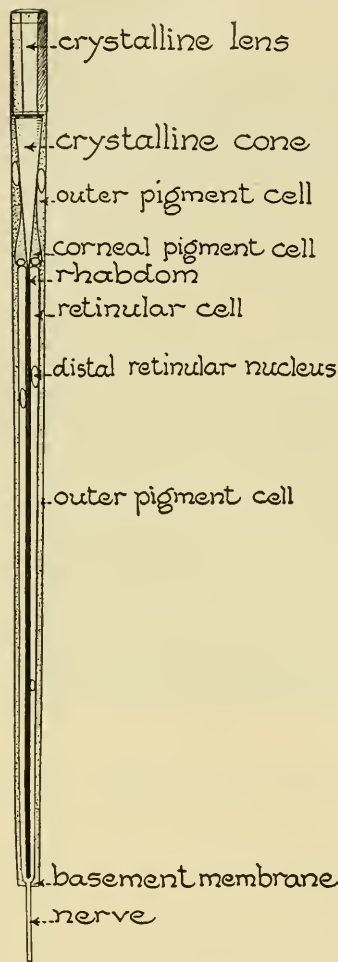


I. Head of worker, lateral view, mouth part labeled. II. Head of worker, lower view, lower part of proboscis cut away. (Compare these mouth parts with those of the locust. Which shows the more primitive condition?)

of the antennae. The queen has about 1600 of these pits on each antenna, the workers about 2400, and the drones about 37,800. This large number probably makes it possible for the drones to find the queen during her nuptial flight, at which time sperm cells are placed within her body so as to insure fertilization of the eggs as they are laid.

The eyes of the bee, as well as those of other insects and crustaceans, are compound. This means that they are composed of individual units called *ommatidia*. Each ommatidium consists of the *retinula*, a group of elongated sensory cells, which encloses a rodlike *rhabdom*, the latter made up of the sensory edges of the *retinal cells*. At the outer edge is a *corneal lens*, under which is formed a *crystalline cone*. The retinal cells are connected with the optic nerve fibers, the entire apparatus being covered with a layer of pigment cells, so that each ommatidium is a unit, and according to experimental evidence, is

used as a single eye, in conjunction with the several hundred others in the compound eye. Such eyes are not very efficient. It is probable



Detail of an ommatidium.

that they do not have any sharp vision for distant objects and not very clear vision for near objects. Bees have been conditioned to visit boxes of different-colored flowers in order to get honey, but recent experiments by Lutz and others indicate that they are guided to flowers by odor rather than by color.

Bees also have a tactile sense which comes through tactile hairs on various parts of the body, these hairs being most numerous on the antennae.

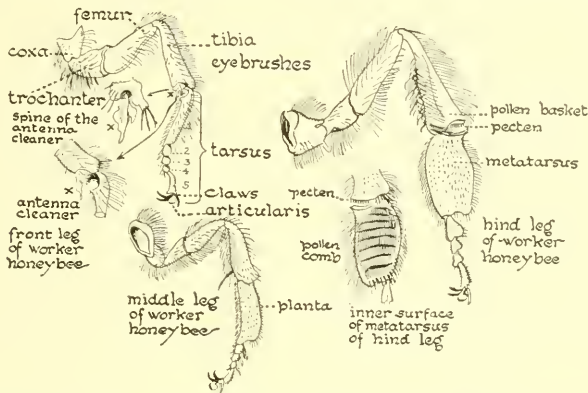
The Thorax and Its Appendages

The entire body of the bee is covered with hairs, which indirectly play an important part in pollen collection and cross pollination, for the bee in rubbing against the stamens of a flower gets a good deal of pollen on the head and back. The thorax is armored and thus serves well its purpose as a base for the attachment of legs and wings. The delicate membranous wings, with their ramifying veins and veinlets serving as supporting structures, are outgrowths from the body wall and hence not true appendages. A wing in flight describes a figure eight course, its rapid movements being caused by four pairs of muscles.

The legs have most interesting special adaptations for the several trades which the worker bee carries on. It is a typical insect leg, of five divisions consisting of a heavy basal *coxa*, a short piece called the *trochanter*, a long *femur* which with the adjoining *tibia* is provided with long hairs, and a five-jointed *tarsus*. The tarsus is provided at the tip with a pair of strong claws, between which

is found an adhesive organ that enables the animal to hold fast to slippery surfaces.

Each pair of legs bears different structures which are of use in pollen gathering and the making of wax. The anterior pair of legs has along the anterior margin of the tibia a fringe of short, stiff hairs, *eye brushes*, used for cleaning pollen or other materials from the compound eyes.



These appendages are used for more purposes than locomotion. Find all the adaptations shown and give the use of each adaptation to the bee.

The first joint of the tarsus is provided with long hairs which form a *pollen brush*. This is used to collect pollen grains scattered over the hairs of the body. At the base of the first joint of the tarsus is a semicircular notch lined with short, stiff bristles, while a flat spur projects from the distal end of the tibia. This apparatus is the *antennae cleaner*. To accomplish this function the front leg is extended with the notch placed at the base of the antenna, which when drawn backward through the notch is effectively cleaned of pollen.

The middle pair of legs is not so highly specialized as the anterior pair. There is a large spine near the outer end of the tibia which is used as a pick for removing flakes of wax secreted from the wax pockets located under the abdomen. The flattened basal segment of the tarsus is called the *planta*. Its hairy surface is used for brushing pollen from the body hairs.

The hind legs are larger and broader than the two anterior pairs. They carry most of the pollen gathered from flowers to the hive. The slightly concave outer surface of the tibia, called the *pollen basket*, is lined by long outward-curving hairs, and may often be seen

filled with pollen in bees returning to the hive. The inner surface of the first tarsal segment, or *metatarsus*, is covered with rows of stiff bristles forming the *pollen comb*, while the lower edge of the tibia ends in a row of spines, called the *pecten*. The pecten of one leg is scraped over the pollen comb of the opposite leg, the pollen thus obtained being pushed up into the pollen basket by means of a little projection on the upper edge of the metatarsus.

Honey Manufacture

Although bees make honey, which is a good energy-releasing food, they do not live entirely upon it because of its lack of proteins needed for building up the body. Both adults and larvae use pollen moistened with saliva and honey, which forms "bee bread." Bees suck up nectar from flowers, pass it through the esophagus into a thin-walled *crop*, or *honey stomach*. This organ is an extensile sac which when filled holds only a drop or two of fluid so that numerous trips to and from the hive are necessary to fill a single cell of honeycomb. The gathered nectar remains in the honey stomach until the bee returns to the hive, when it is regurgitated and placed in the cells of the honeycomb. As honey, it is still too watery, so some of the workers, by a rapid vibration of their wings, cause enough water to evaporate to bring it to the right consistency. Just before the honey is capped in the comb, the worker places a minute amount of formic acid from its poison glands in the cell. This aids in the preservation of the honey. Bees store somewhat over two pounds of honey a day for the average hive. This is in addition to what the adults eat and what is fed the young. Honey storage, of course, varies with the weather. Bees, like human outdoor laborers, do not work on rainy days.

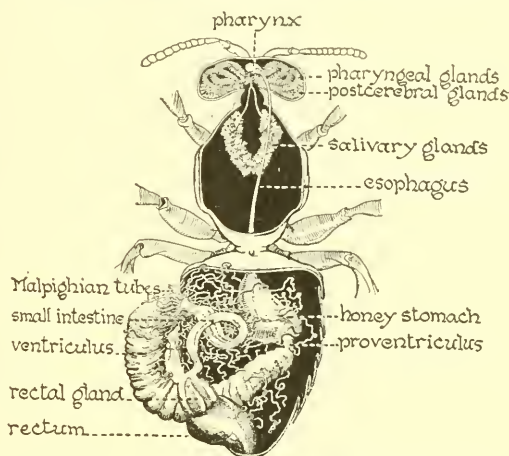
Dr. L. Armbruster of Berlin made some interesting computations on the number of visits of bees to flowers necessary to store up about two and one half pounds of honey. He found that bees have to visit at least 6,000,000 clover heads, as clover honey seems to require the most work. Peas, at the bottom of the scale, called for as low as 80,000 visits from the bees, and other honey-producing plants fell within these two limits. Among the most important honey-producing plants are white clover, buckwheat, and fruit trees in the East and North; alfalfa, sweet clover, and a few trees, as the tulip tree, in the Central West; the citrus fruits, palmettos, and mangrove in the South; and alfalfa, sages, citrus and other fruit trees in the far West.

Digestion, Circulation, Respiration, and Excretion

The digestive tract posterior to the crop has to do with the digestion of food. The stomach, a large cylindrical structure, has a valvelike arrangement between it and the crop to prevent nectar not used as food from going further. It leads into a small intestine, which in turn expands to form the rectum at the posterior end of the body.

Attached to the anterior end of the intestine is a circle of *Malpighian tubules*, about one hundred in number, named after their discoverer, Marcello Malpighi, who first pictured them in his *Anatomy of the Silkworm* published in 1669. The tubules are excretory in nature, as is proven by the fact that small crystals of nitrogenous wastes are formed in them.

In the insects and crustaceans, there is no



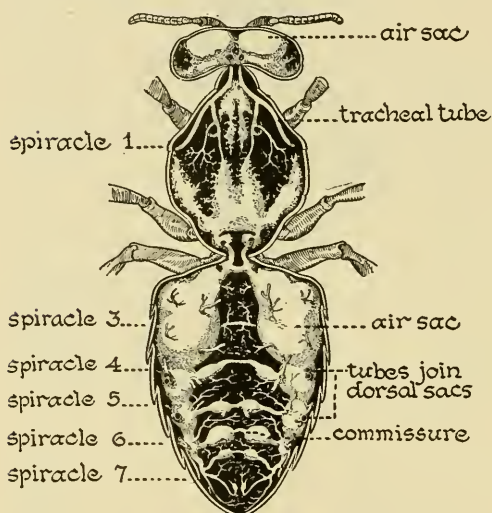
The food tube of worker bee and glands connected with it. The pharyngeal glands form the royal jelly or brood food given to the larvae by the workers. The postcerebral glands secrete a fatty substance, which is thought to be mixed with wax in making honeycomb. The salivary glands are true digestive glands. (After Snodgrass.)

closed system of blood vessels as was found in the earthworm, but in the former there is a well-developed, dorsally placed, tubular heart, located in the abdomen and perforated by paired openings, or *ostia*, through which blood enters. Blood is forced out of the anterior end into spaces, or *sinuses*, which in the insects are found throughout the body cavity and take the place of blood vessels. The heart acts somewhat like a rubber bulb syringe in a pail of water, serving, along with the muscular movements of the insect, to keep the blood in motion through the blood sinuses. Snodgrass¹ shows that there is a rapid and complete circulation of blood through the main sinuses, the blood being forced backward into the abdomen on the ventral side of the body by the pulsat-

¹ Snodgrass, *Anatomy and Physiology of the Honey Bee*, McGraw-Hill, 1925, pp. 189-190.

ing vibrations of the so-called *ventral diaphragm*, a sheet of thin tissue which is stretched across the ventral part of the abdominal cavity, while on the dorsal side it is pumped by the heart toward the anterior end of the body. The blood, which bathes all the tissues, consists of a *plasma*, and colorless blood corpuscles or *leucocytes*. The plasma is rich in food substances, but there are no oxygen-carrying substances in it, so that insect blood only carries foods and wastes.

Oxygen is brought directly to the tissues by a very efficient type of respiratory organ, the so-called *tracheae* and their branches. Along the sides of the thorax and abdomen of insects are found paired openings called *spiracles*. In the worker bee there are ten pairs of



A portion of the tracheal system of the worker bee. The dorsal trachea and air sacs have been removed. Three spiracles are not shown. What advantages are there in having this type of respiratory system? (After Snodgrass.)

these openings, three pairs in the thorax and seven in the abdomen. The spiracle is an oval opening which can be opened and closed by means of a flat plate attached to its rim. Each spiracle leads into a tracheal tube, the wall of which is strengthened by a spiral thread of chitin, thus keeping the tube filled with air. These tubes branch again and again until they finally end in tiny tubules between the body cells. Expansion and contraction of the muscles of the body wall force air in and out

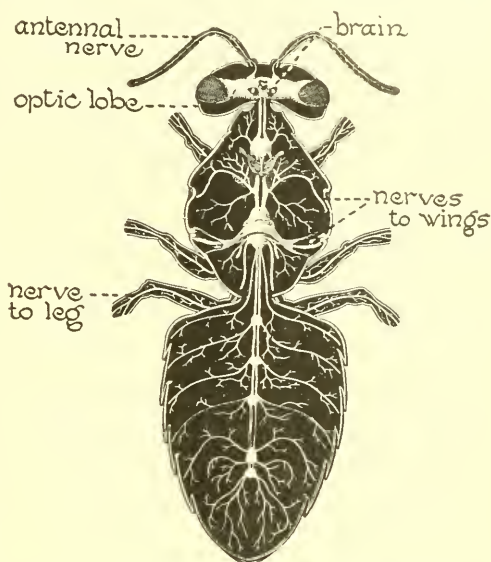
through the tracheae, thus securing circulation of oxygen to all body cells. In addition to the tracheae, large air sacs are developed in the thorax and abdomen, as are seen in the above diagram. Since insects that fly rapidly usually have better developed air sacs than those that are sedentary, it is evident that the air sacs must serve to "lighten the load" of the body in its flight as a heavier-than-air machine.

The Nervous System

The nervous system of the bee is well developed, consisting of a series of ganglia, forming a double ventral nerve cord with a dorsal *cerebral ganglion* (brain), connected by a *circum-esophageal nerve ring* with a *subesophageal ganglion* directly underneath it.

Although typically in a segmented animal there should be one ganglion for each segment, we find fewer ganglia than segments in the adult bee.

This is because certain of the ganglia have fused, there being seven in the ventral nerve cord of the bee. From each of these nerves *efferent fibers* extend to the muscles while *afferent fibers* from sense cells end in the ganglia to make up the reflex arc previously described (page 195). Not all co-ordi-



Nervous system of worker bee. Why are the ganglia in the thorax so much larger than those of the abdomen? Note that the brain is on the dorsal side, the esophagus (not shown) passing between the two nerves that connect it with the first thoracic ganglion. (After Snodgrass.)

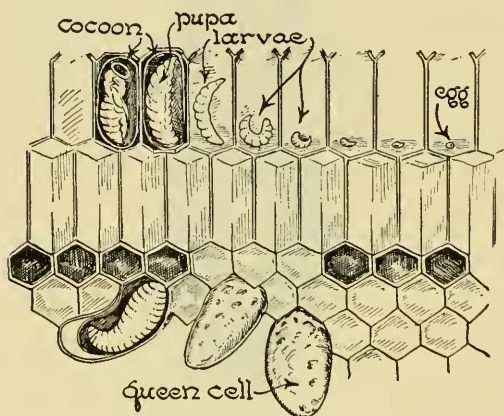
nation of muscles is controlled by the brain, for a headless bee will still walk and experiments have shown that the body ganglia are independent centers of control over the appendages. Insects of the order Hymenoptera, to which the bee belongs, have the best brain development of any of the insects, a fact that seems to be correlated with their complex social habits and their keen senses.

Reproduction and Life History

Although the workers possess undeveloped ovaries, all the eggs are laid by the fertile female or queen. While a worker may live about six weeks in summer and never more than a few months, the queen lives three or four years, or even longer. The ovaries of the queen are made up of a number of tubules, in which are eggs in all stages of

development. The fully developed eggs pass out through the *oviduct* into the *vagina*, where they are fertilized by sperm cells that were placed in a sac called the *seminal receptacle* by a drone during the nuptial flight of the queen. The drones form the sperm cells in two *testes*, but the sperms are stored in *seminal vesicles* from which, during mating, they are transferred to the seminal receptacles of the queen.

The queen lays fertilized eggs in honeycomb cells of the worker and unfertilized eggs in the larger drone cells. Just how she controls



Cells of hive of honey bee. Note the stages in development of worker. How many kinds of cells are shown? (Read page 213.)

the actual fertilization of the egg is not known. According to Nolan,¹ the queen produces an average of about 900 eggs a day during the season, but may lay as many as 2000 a day during the period of greatest honey making. The queen places the eggs in the cells by means of an *ovipositor*, which in the workers is modified into a *sting*. The latter structure is made up of two darts,

closely applied to each other so as to form a tube through which poison from a poison sac flows when the darts are forced out of their sheath as the bee stings. Two different poisons are produced, one of which is formic acid, the other an alkaline substance. Worker bees usually die after stinging, as the sting with its attached parts, along with some of the intestine, is left in the wound. The queen, which also has a sting, uses it only in combat with other queens and does not lose her life in its use.

The life history of the bee is rather brief. Three days after fertilization the egg hatches into a *larva* which lies in the cell surrounded by a plentiful supply of "bee milk," a mixture of digested honey, pollen, and saliva. After three days of feeding by the young "nurse" bees, the larvae are given more and more undigested food. Drones are

¹ Nolan, "Egg-laying Rate of the Queen Bee." *Gleanings in Bee Culture*, Vol. 52, 1924, pp. 428-431.

fed undigested honey and pollen after the fourth day, while young queens are fed upon an especially nutritious albuminous "royal jelly" until they pupate. During the larval period, the young insects grow rapidly, changing their skins or molting several times during the process. About the end of the fifth day the larvae are given their last food by the attendant bees and the cell is capped with wax. Then the larva spins a cocoon, molts for the last time, and becomes a *pupa*. In this stage it begins to assume adult characters and, after the next molt, emerges from the cell as an adult. This process, in which the insect undergoes certain changes not in line with its direct development, is called a *metamorphosis*. The last molt in which the young adult is ready to emerge from the cell takes place about 20 days from the time the egg was laid. The young adult bee, or *imago*, chews its way out of the cell, usually emerging on the 21st day. The metamorphosis of the drone takes 24 days and the queen 16, the greater rapidity of the latter probably being due to the more nutritious food received.

The Life in the Hive

The activities in a bee hive are numerous and interesting. Besides collecting nectar and pollen and making honey, the most important work is that of building the wax cells of the comb. Wax is secreted by the wax glands on the abdomen and transferred to the mouths of the workers, where it is mixed with saliva, kneaded by the mandibles, and shaped into the familiar hexagonal cells of the honeycomb. Six kinds of cells are made: (a) drone cells, (b) worker cells, (c) queen cells, (d) transition cells between worker and drone cells, (e) attachment cells which fasten the comb in place, and (f) honey cells. Worker bees also bring back *propolis* or "bee glue," resinous materials collected largely from the buds of trees. The propolis is used to fill up cracks in the hive and to strengthen the comb. Water is also carried to the hive in dry, hot weather. Besides the above activities, others must be performed if life in the hive is to go on. The workers must have plenty of fresh air, for they do hard work. To this end certain of the bees are delegated to the task of vibrating their wings rapidly, thus creating currents of air through the hive. Some workers rid the hive of excreta, dead bees, or any other substances that interfere with its cleanliness. Still other bees guard the entrance of the hive against such enemies as bee moths or yellow-jacket hornets, which come to steal honey.

One other activity is that of *swarming*. In early summer, the hive frequently becomes overcrowded, and when such conditions arise several queen cells are built and young queens are raised. When a young queen hatches, the old queen gathers together several thousand of the workers, who fill their honey stomachs with honey and then set out to form a new colony. Sometimes scouts are sent out in advance to seek a place for the new hive, which may be in a hollow tree. Often the swarm, forming a large ball about the queen, will come to rest on the branch of a tree and the beekeeper may then hive it in an artificial hive. It is interesting to note that our honey bee (*Apis mellifica*) is an emigrant from Europe and that there are no native honey bees in this country.

This social life with its accompanying division of labor is seen in varying degrees all through the order Hymenoptera. Beginning with the solitary bees, we find increasing social complexity of life until, in the ants, a highly organized group is developed having several different kinds of workers, soldiers, and males. If you want fascinating reading along this line, look into William Beebe's *Jungle Life*, or better, into Wheeler's masterly volume on *Ants*.

SUGGESTED READINGS

Carpenter, G. H., *The Biology of Insects*, The Macmillan Co., 1928.

Chapters II, III, IV, V, VII, and IX make interesting reading.

Fernald, H. T., *Applied Entomology*, McGraw-Hill Book Co., 1935. Chs. IV, V, and XXXIII.

A useful book of reference.

Kellogg, V. L., *American Insects*, Henry Holt & Co., 1908.

Still an authentic book of reference.

Metcalf, C. L., and Flint, W. P., *Fundamentals of Insect Life*, McGraw-Hill Book Co., 1932. Chs. II, IV, and V.

Plath, O. E., *Bumblebees and Their Ways*, The Macmillan Co., 1934.

A fascinating study of one type of social insect.

Snodgrass, R. E., *Anatomy and Physiology of the Honeybee*, McGraw-Hill Book Co., 1925.

Parts of Chapters II, III, and IV are particularly useful, but a student can cull much from the entire book.

Wells, H. G., Huxley, J. S., Wells, G. P., *The Science of Life*, Doubleday, Doran & Co., 1931.

Pp. 1147-1182 give one phase of insect life worth reading about.

XII

THE ART OF PARASITISM

PREVIEW. Who qualifies? · Some host-parasite relationships: The host-parasite conflict; effects of a parasitic life; keeping the cycle going · The complexity of parasitic relationships: External parasites; temporary parasites, periodic parasites, permanent parasites; internal parasites; parasites requiring one host, parasites requiring two hosts, malaria, parasites requiring more than two hosts · Suggested readings.

PREVIEW

According to the definition, a parasite is one that “lives on or within, and at the expense of some other organism,” and thus might include forms from the smallest, such as filtrable viruses and bacteria, to some of the largest species. As a matter of fact, parasitism is well-nigh universal, for examples are found among nearly all groups of plants and animals.

In many instances there appears to be a remarkable balance between the parasite and its host. A dead host is of little use to a parasite since it implies a loss of free transportation as well as board and lodging. Consequently the existence of a parasite must be a compromise, for it must be able to secure enough nourishment to maintain and reproduce itself and yet do this either without injuring too much the vitality of its host, or actually reducing its own numbers. As a result of this rather elaborate compromise parasites have become so adapted that they usually destroy only small portions of the host tissue which usually can be replaced by regeneration.

Whenever a parasite reaches a final host, the problem of propagation arises. Most parasites produce large numbers of eggs, cysts, or spores that are discharged with the waste products of the host. Through the medium of food or drink, these reach the next host, which is sometimes intermediate or secondary, the parasites thus becoming dependent upon the food habits of more than one organism to maintain their cycles.

Most animal parasites are essentially carnivorous in their feeding habits. True carnivores, however, destroy their prey, whereas parasites as a rule do not, and while carnivores are much larger than their prey, parasites are smaller. Elton says, to summarize, “The

difference between the methods of a carnivore and a parasite is simply the difference between living upon capital and upon income ; between the habits of the beaver, which cuts down a whole tree a hundred years old, and the bark beetle, which levies a daily toll from the tissues of the tree ; between the burglar and the blackmailer. The general result is the same, although the methods employed are different.”¹

Who Qualifies?

Parasites vary greatly in their types of relationships. Some may be classified as either *internal* or *external*, according to their location in or upon the host. They may be otherwise classified as *temporary*, or free-living during a part of their life cycles ; *permanent*, or parasitic throughout their lifespan ; and *periodic*, only visiting their hosts to obtain nourishment. Actually there are almost as many gradations and variations in the degree of parasitism among animals and plants as there are kinds of parasites. Mosquitoes and some fleas visit their hosts just long enough to satisfy their appetites. The cattle tick, *Boöphilus annulatus*, never leaves its host except when ready to lay eggs. Scab mites and some lice are permanent, living upon the same host from one generation to the next, only leaving or being transferred by direct contact. In between these extremes occur such well-known forms as the hookworm, which has a free-living larval stage, and the botflies that pass their larval existence as parasites.



Wright Pierce

Dodder, an example of a plant parasite which starts life as a self-respecting plant growing in soil.

Among plants, the large and heterogeneous group of bacteria exhibit many varieties of parasitism, while higher in the plant scale such forms as dodder and broomrape exemplify true parasitism. Other groups are partially parasitic during their life cycle.

Among plants, the large and heterogeneous group of bacteria exhibit many varieties of parasitism, while higher in the plant scale such forms as dodder and broomrape exemplify true parasitism. Other groups are partially parasitic during their life cycle.

¹ From Elton, C., *Animal Ecology*. By permission of The Macmillan Company, 1935.

Some Host-Parasite Relationships

In the event of parasitism, the association is definitely in favor of the parasite, since it usually "lives on" the second party concerned, the *host*. Such a relationship constitutes a fourth type of habitat, namely *parasitic*, that is available to both plants and animals along with the well-recognized terrestrial, fresh-water, and marine habitats. That many organisms take advantage of this type of existence may be clearly proved by observing the plants and animals of any locality.

The Host-Parasite Conflict

Theoretically a conflict exists between the parasite and the host. The latter has as its chief weapon a *lytic* or dissolving power which is a normal physiological reaction. Likewise the weapons that probably were first brought by the parasite from its hypothetical free living ancestral state must also have been of a lytic, toxic, or otherwise destructive nature. In many cases the host seems to have adapted itself to bear the burden of parasitism with the least possible outlay of energy on its own part, so that eventually there has developed a balance between the two organisms, which might be called a *host-parasite equilibrium*. In order to reach this equilibrium the parasite has likewise gradually evolved some sort of protective device, often a capsule which becomes interpolated in the cycle, or an *anti-enzyme* or *anticoagulin* to counteract the destructive action of the host's secretions, thus necessitating a counter attack upon the part of the host. This apparently was made, first, through the over-



Wright Pierce

The large masses in this tree represent a true plant parasite, the mistletoe.

development of the host mechanism which elaborates specific protective substances called *antibodies*, and secondly, through "the adaptation of certain normally phagocytic cell groups to the internment and gradual destruction of the parasite."¹

Sometimes the introduction of a parasite has a visible effect upon the host. In the case of certain gall insects, such as the *Cynipoidea*, the deposition of an egg by the female in a plant tissue, or the subsequent movement of the larva, furnishes the stimulus which causes



Wright Pierce

Unopened oak gall beside one which has been opened to show the enclosed larvae.

abnormal proliferation of tissue, resulting in the enclosing of the insect larva and the production of a so-called *gall*. The type of gall produced on a given plant appears to be specific, whether it occurs in root, leaf, twig, or stem. Usually a gall ceases to grow about the time when the enclosed larva finishes feeding. In such instances it dries and forms a protective covering inside of which the insect pupates, ultimately gnawing its way out.

Effects of a Parasitic Life

Parasitism as a biological phenomenon probably has a more far-reaching effect upon the structure of the parasite than upon the host. In the first place the former no longer has to worry about locomotion or the securing of food because these two important functions are taken care of by the host. Consequently a gradual simplification of the organs of a parasite takes place, until in forms like the tape-

¹ Smith, T., *Parasitism and Disease*, Princeton Univ. Press, 1934, p. 111.

worm, and the spiny-headed worm, for example, there is no trace whatever of a digestive tract in the adult. Such worms, however, have access to various digested foods which are ready for absorption by the host and it appears certain that these gutless forms must be able to absorb and utilize materials from the alimentary canal of their benefactor. Other worms, such as the flukes or trematodes, and roundworms, possess a well-developed alimentary canal, the secretions of which, in some instances at least, cause a liquefaction of the tissue in the immediate vicinity of the parasite, thus making it available as food for the organism.

Another problem which parasites have had to solve is that of respiration. In the case of cellular or blood-inhabiting forms the parasite obviously has access to plenty of oxygen, whereas intestinal parasites face a difficulty, since the alimentary canal is known to contain little oxygen. Many investigators now believe that these worms secure their energy from the breakdown of dextrose. This substance results from the hydrolysis of more complex carbohydrates and is the form in which it is absorbed from the intestine into the blood stream. Presumably oxygen is secured during the process of anaerobic fermentation that results in the splitting of dextrose or glycogen (if the carbohydrate has been converted into glycogen during the metabolism of the parasite) into fatty acids and carbon dioxide. This type of metabolism is characteristic of some bacteria and yeasts.

One of the most striking effects of the parasitic habit lies in the tremendous development of the reproductive capacity of the parasite, a process undoubtedly correlated with the numerous hazards which must be met if its life cycle is to be completed. The development occurs in two ways, — first by the production of enormous numbers of eggs, and secondly by the interpolation of asexual stages in the cycle. Thus it has been estimated that a single free-swimming, ciliated stage (*miracidium*) of a fluke may be the indirect parent of as many as 10,000 free-swimming, tailed larvae (*cercariae*).

External or *ectoparasites* also show marked evidence of adaptation to their type of existence, as shown by the piercing and sucking mouth parts of the parasitically inclined arthropods or the degeneration of the mouth parts in the case of the adult botflies, as well as by the laterally compressed body of the flea, and the loss of wings in lice and bedbugs. Limitation as to the host and as to the location on the host shows specialization among this group. These factors tend to illustrate stages in the development of ectoparasitism.

Keeping the Cycle Going

The chief problem of any species centers about maintaining itself, a statement to which there is no exception in the world of parasites. Obviously those organisms which have become adapted as ectoparasites are not faced with complicated problems relating to the transfer from host to host. By means of simple contact a new host may be reached, or if a portion of the life cycle of the parasite is free living, it may leave the host to deposit its eggs. Even in cases where the eggs are laid among hairs of the host they usually fall to the ground to develop.

A more difficult problem of maintaining the species must be faced when internal parasites are involved. Bacteria which are capable of producing protective capsules or spores of one sort or another are tided over unfavorable periods and so aided in reaching new hosts. They are adapted also for rapid reproduction. One worker has estimated that if the multiplication of bacteria were unchecked one cell would be the parent of 281,500,000,000 bacteria in two days. Such a mass at the end of the third day would weigh about 148,356,000 pounds.

Many parasitic protozoa as well as metazoa are adapted to be transferred from one host to the next by means of resistant cysts secreted by the organism. Others, like the blood-inhabiting trypanosomes or malarial organisms, secure transference by adapting themselves to insects which act as wholesale distributors for the parasites. Some produce harmful toxins which occasionally kill the host. In such instances, however, one may be sure that the host is abnormal and the parasites have not become adapted to it. In the case of the trypanosomes of man in Africa, antelopes are their natural hosts and are quite tolerant to these blood parasites. Since man and domestic animals are unnatural hosts, they are consequently much more severely affected by them.

The Complexity of Parasitic Relationships

The most satisfactory way to secure a general idea of the surprisingly varied adaptations to a parasitic existence is by a study of a few examples. Such a study emphasizes clearly the almost uncanny adaptations which have been made by parasites to insure the completion of their life cycles. While various types of parasitism clearly exist, nevertheless the line that demarks one kind of parasite from

another may not always be sharply drawn. However, for the sake of convenience an attempt will be made to outline briefly a few examples of such relationships.

External Parasites

External parasites are found throughout the plant and animal kingdoms. Even among the minute protozoa, ectoparasitic organisms occur, such as *Cyclochacta*, a parasite on fishes, which may cause an appreciable economic loss under epidemic conditions. The lamprey eel among the chordates is a large external parasite on certain fishes.

For the sake of convenience, external parasites may be classified as to whether they are temporary, periodic, or permanent. Some forms, like the house fly, do not really belong in any of these categories. Yet the house fly certainly deserves



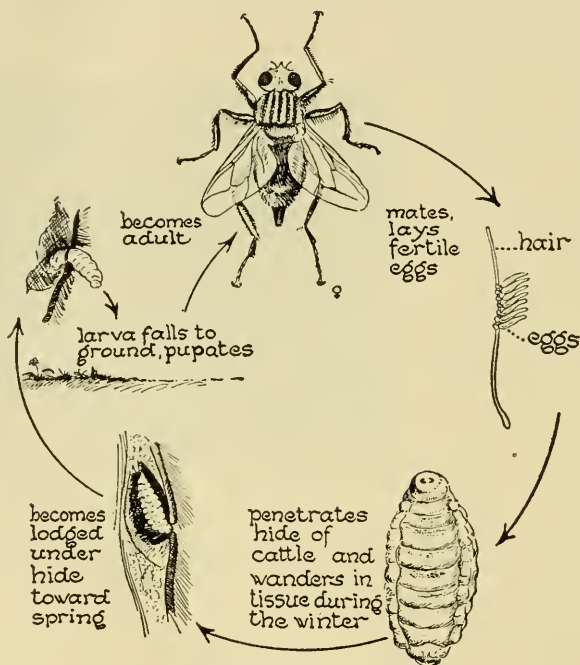
American Museum of Natural History

These brook lampreys are close relatives of a larger form which frequently attacks fish and remains as a temporary external parasite until the host is destroyed. What type of mouth is characteristic of this group?

mention, since it serves as a *mechanical carrier* from one host to another for the transfer of numerous bacteria and their spores, as well as the cysts and eggs of various other parasites.

TEMPORARY PARASITES. As an example of temporary parasitism may be mentioned the parasitic Hymenoptera that lay their eggs on the eggs, larvae, or even the adults of other insects. During the developmental interlude they remain as true parasites within the body of the host until they eventually destroy it, at which time they cease their parasitic existence and become free living. The ichneumon flies, that belong in this group of parasitic Hymenoptera, each year attack and destroy great numbers of injurious as well as some beneficial insects. Another example of a temporary parasite is the ox botfly, the free living adult of which attaches its eggs to hairs on the legs of cattle. Upon hatching, the larvae penetrate the hide and

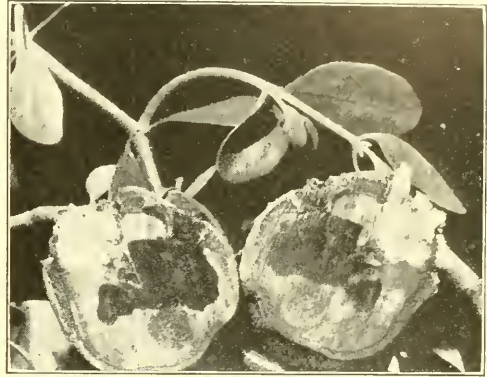
wander through the underlying tissues of the host until in the spring of the year they come to lie beneath the skin, which is soon punctured to serve as an air vent. Finally, when the larvae are full grown they burrow out, fall to the ground, and there pupate, finally emerging as adult free living flies, destined to ruin many million dollars' worth of hides annually.



Life cycle of the ox botfly.

PERIODIC PARASITES. Other arthropods definitely fall into the group of those that are periodically parasitic. Such forms are predators, and most of them are blood suckers, in which manner they may serve as a link in a chain of parasitism. Thus the female mosquito serves as the carrier for organisms that cause malaria, yellow fever, and filariasis. Others like the tick or rat flea may not only secure a meal of blood from one host but at the same time be the means of transmitting Rocky Mountain spotted fever or bubonic plague to some other host. Certain species fall into the realm of parasites by their own right, the tick and botfly clearly belonging in this latter group.

PERMANENT PARASITES. Comparatively few organisms belong in this category. Some of the flukes with a continuous life cycle like the marine *Epidella melleni*, or the gill fluke, *Ancyrocephalus*, pass their entire cycle upon the same host, adding their progeny to the same animal and so on *ad infinitum*. Similarly, the female head louse that cements her eggs, or "nits," to human hair from which newly hatched lice appear within six to ten days is another example of a permanent parasite. The new additions to the community of head lice must soon feed upon the roots of the host's hair or else they will die.



Wright Pierce

Longitudinal section showing mistletoe invading the tissues of its host.

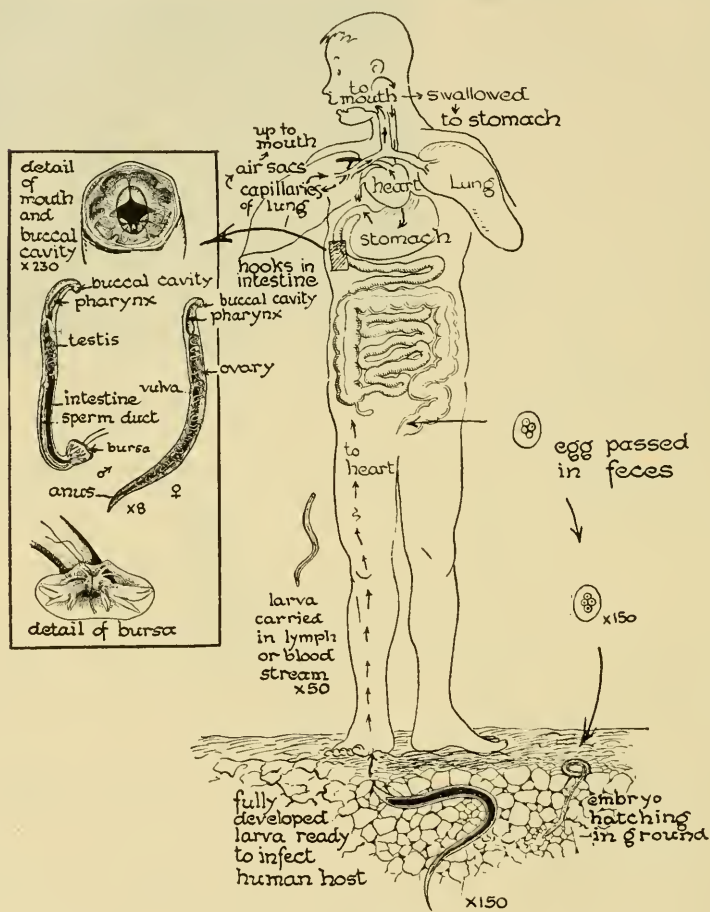
The parasitical mistletoe is practically permanent in habit, since it not only taps the life-giving fluids of its host but also lives for many years upon the same tree.

Internal Parasites

The food cycle plays a vital rôle in the dispersal of all internal animal parasites. It frequently happens that animals which suck the juices of plants or the blood of other animals play an important part as an intermediate host. It should be borne in mind that when carnivores are included in the chain of parasitism, the cycle tends toward greater complexity. A few examples will serve to illustrate this point.

PARASITES REQUIRING ONE HOST. The adult hookworm, *Necator americanus*, lives in the small intestine of man, where the adult female is attached to the walls of the intestine and produces great numbers of eggs which are eliminated from the digestive tract in the early developmental stages. Under proper conditions of soil, temperature, and moisture, development of the larvae proceeds rapidly, so that hatching may take place within 24 hours. The small larval form is only about 0.25 mm. in length, but by the end of the third day it has nearly doubled in length and soon molts twice, then being in the

infective stage. Hookworm larvae may enter the body in food or drink, but the normal method of entry is by actively boring through the skin of the human hand or foot. For this reason the disease is called "ground itch" because of the inflamed areas caused by the



Life cycle of the hookworm.

entrance of the larvae. Once having effected entrance into the host, the minute worms are passively carried through the blood stream to the heart and thence to the lungs, where they migrate out from the capillaries of the lungs and work their way through the delicate walls of the air sacs into the lung cavities. They next migrate up

the lung passages over the "saddle" to the esophagus, and there are swallowed, reaching the stomach and eventually the intestine. Within the next fortnight two more molts occur, after which the parasites reach maturity, copulate, produce eggs, and continue the cycle.

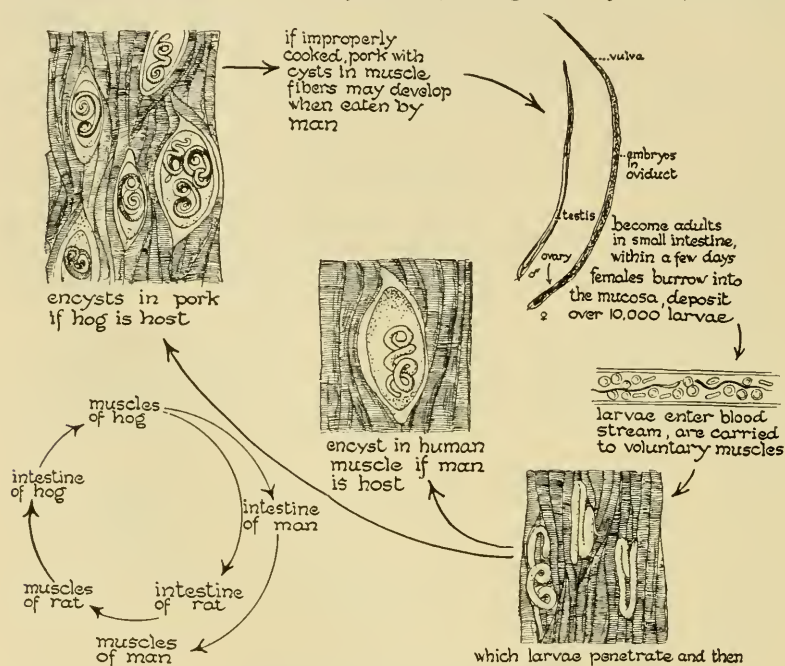
The large roundworm, *Ascaris lumbricoides*, lays eggs which develop into infective embryos within three weeks under proper conditions of temperature and moisture. After reaching the digestive tract of the host together with food or drink, the newly hatched larva burrows through the mucous layer and starts on a "10-day tour" following essentially the same itinerary as that of the hookworm.

Among the protozoa the Ameba, *Endameba histolytica*, the cause of amebic dysentery, is transmitted from one human host to another and thence to the outside world, and back again to the human large intestine by means of resistant cysts carried in contaminated food and drink.

PARASITES REQUIRING TWO HOSTS. The dread pork roundworm, *Trichinella spiralis*, while a permanent parasite having a relatively simple life cycle, nevertheless requires two hosts to complete its cycle. The encysted larvae occur in a variety of hosts, but are normally secured by man through eating insufficiently cooked pork. The parasites mature rapidly in the small intestine and reproduce within twenty-four to forty-eight hours of their arrival. Each viviparous female produces between 10,000 and 15,000 larvae, which are deposited directly in the lymph or capillaries lining the intestine, and are thus circulated by the blood until they reach the voluntary muscles of the body. There, these minute roundworms leave the blood stream, enter the muscle fibers, where within a month a lemon-shaped cyst is deposited about them. Since man is not cannibalistic, the introduction of these parasites into his body becomes a blind alley so far as completing the life cycle is concerned. Unfortunately, when these parasites are once established in the body, there is no way of getting rid of them. In due course of time, calcium carbonate is deposited about the cyst and eventually the parasite dies, but the obnoxious cyst remains to remind the infected person of his injudicious meal by frequent muscular pains which may accompany this infection for years. The normal hosts of *Trichinella* seem to be the rat, mouse, and pig. The former are commonly found in numbers about slaughter houses and the percentage of their infection is usually

high. A great number of other animals have been experimentally infected.

Nearly all of the taenioid tapeworms have a rather simple life cycle. In the case of the beef and pork tapeworms, for example, the infective stage occurs in the flesh of the host in a milky white cyst. When this larval tapeworm, or *cysticercus*, consisting of an inverted head or *scolex* and its outer cyst wall, is ingested by man, the head



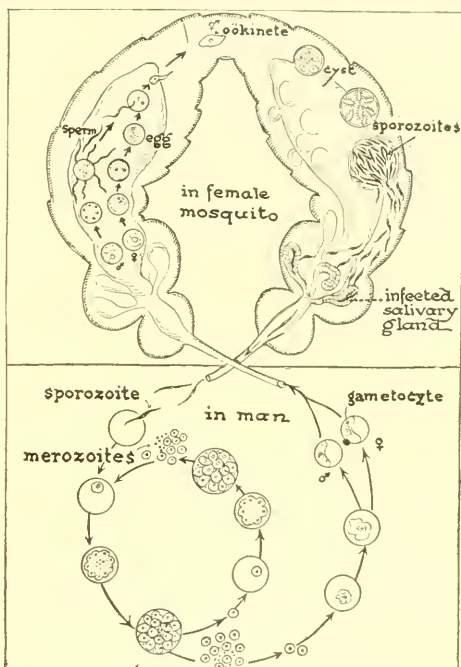
The life cycle of *Trichinella*.

becomes everted, and then attached to the intestinal wall, where the worm starts budding segments or *proglottids* and soon reaches sexual maturity. Proglottids of *Taenia saginata*, or proglottids together with free eggs in the case of *T. solium*, are passed with the feces and, when eaten by the proper intermediate host, develop into cysticerci. Cattle, buffalo, giraffes, and llamas may harbor the larval form of the beef tapeworm, while the hog, camel, monkey, dog, and man are the only known hosts for the pork tapeworm. The chief difference between the cycle of these two parasites centers around the possibility of auto-infection in the case of the latter. This occurs by ingesting the eggs destined for the outside, which hatch in the intestines,

migrate to the blood stream and so reach various parts of the body, there producing cysticerci. As in the case of *Trichinella*, human infection really becomes a blind alley for the parasite.

MALARIA. One of the most economically important parasites is the causative organism of malaria, a minute spore-forming protozoan of the genus *Plasmodium*.

The infective stage, or *sporozoite*, reaches the blood stream of man in the saliva of the mosquito, which is poured into the wound immediately after the victim is punctured. This minute parasite promptly penetrates a red corpuscle and starts to develop asexually, growing until it fills about one half of the corpuscle. It is now ready to undergo the asexual reproductive cycle. The chromatin material is gradually separated into a number of tiny masses, each one of which finally becomes surrounded by a bit of cytoplasm. Growth continues until the red corpuscle is filled with



Life cycle of malaria.

a number of new individuals called *merozoites*. Soon the corpuscle bursts, liberating these merozoites, each one of which seeks out a new corpuscle and begins the asexual cycle all over again.

This asexual cycle recurs regularly, the intervals depending upon the species of parasite infecting the blood stream. Thus in the case of tertian malaria, schizogony is completed every twenty-four hours, while in the quartan type it takes forty-eight hours to complete it. The periodic chills and fever so characteristic of malaria occur at the time of the bursting of the red corpuscles with the subsequent release of the asexually formed merozoites and the accompanying waste matter. Quinine is the most widely used drug to combat the infection as it destroys the newly "hatched" merozoites.

After a number of asexual generations have been produced, special larger, sausage-shaped crescents appear within the red corpuscles. These are the *gametocytes*, or sexual forms. If a female mosquito sucks blood from a person having mature male and female stages of

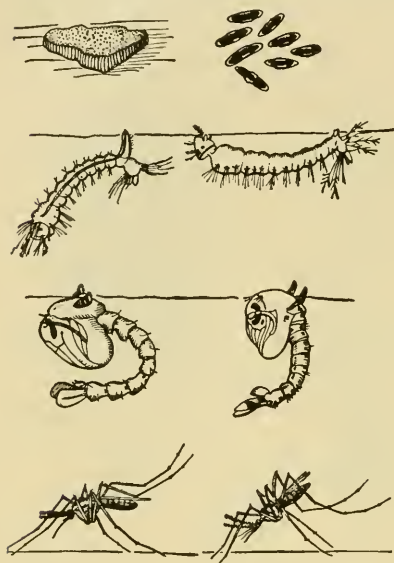


Diagram of eggs, larva, pupa, and adult of *Culex* (left) and the malarial carrying *Anopheles* (right). How could you tell the eggs, larvae, and adults of these two genera apart?

the parasite in the blood, such parasites are taken into the digestive tract of the mosquito, where union of the male and female *gametocytes* takes place. After conjugation the resulting *zygote* forms an *oökinete* or cyst that enters the lining of the stomach of the mosquito, in the outer walls of which a complicated development then ensues for about twelve days, ending with the formation of a large number of spindle-shaped structures called *sporozoites*. The cyst then bursts and the sporozoites migrate to the salivary gland of the mosquito. After that time, if the female mosquito bites an uninfected human host she infects him with the sporozoites, which enter red blood cells.

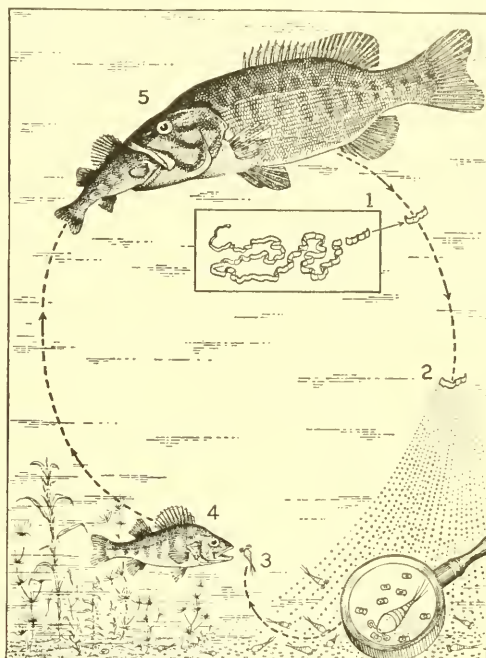
Animals are not the only group having complicated parasitic cycles. The various smuts, mildews, and rusts are plant parasites that annually take their toll throughout the country. Wheat rust is probably one of the most destructive of the parasitic fungi. This rust has been the most dreaded of plant diseases because it destroys the harvest upon which the civilized world is most dependent. Wheat rust has long been associated with barberry bushes. As early as 1760, laws were enacted in New England providing for the destruction of barberry bushes near wheat fields, although nothing was actually known of the relationship between the barberry and rust until comparatively recent years. It is now known that wheat rust may pass part of its life as a parasite on the barberry, whence it migrates to the wheat plant and there undergoes a complicated life history. Since the nourishment and living matter of the wheat are used as food by

the parasite, the plant is weakened and little or no grain is produced. A few of the wheat rusts do not require two hosts but complete their life cycle on wheat alone. Such rusts pass the winter by means of thick-walled spores which may remain in the stubble or in the ground until the young wheat plant appears the following year, or the spores are carried by the wind from other regions.

Parasites Requiring More Than Two Hosts

Tapeworms show a variety of adaptations and exhibit a unique and delicate balance that permits the completion of their various cycles. Roughly they may be divided into two groups, one in which the eggs reach water, subsequently passing through some aquatic organism, and a second in which ova are scattered in the soil and reach the intermediate host by means of food or drink. In the first group are the broad tapeworm of man, the bass tapeworm, and many others, while the second includes the various taenioid worms and their relatives. All of these parasites show a remarkable degree of specialization.

The broad tapeworm of man, *Diphyllobothrium latum*, was brought to this country sometime during the last century by immigrants from the shores of the Baltic Sea. The worm matures in the digestive

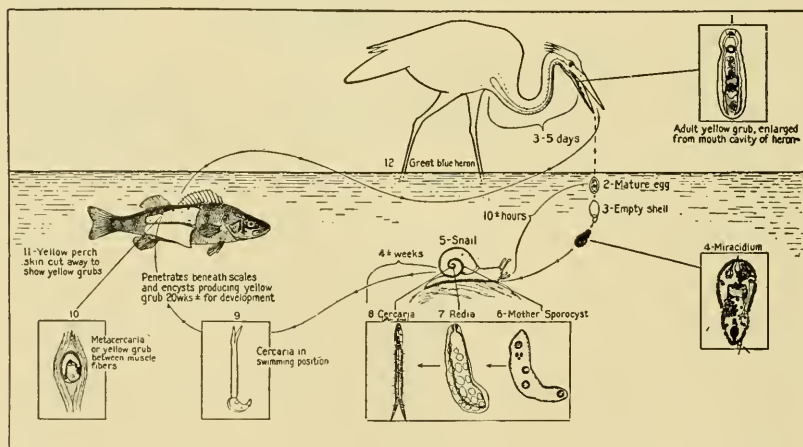


N. Y. State Conservation Depn.

The life cycle of the bass tapeworm (*P. ambloplitis*). (1) The mature tapeworm occurs in the intestines of the large- and small-mouthed bass. (2) Contact with water causes the proglottids to liberate the eggs which are eaten, (3) by various copepods. When infected copepods are eaten by many species of plankton-feeding fish (4) a larval tapeworm (*plerocercoid*) develops in the mesenteries, liver, spleen, or gonads of these fish. Heavy infections in the small-mouthed bass affect reproduction. The tapeworm reaches maturity when fish infected with the larval stage are eaten by larger ones. How could this cycle be controlled in fish hatcheries?

tract of the host, producing a string of as many as 3000 to 4000 segments or *proglottids*, often reaching a length of ten meters. Mature proglottids, passed from the host with the feces, must reach water, where the eggs are shed. After a developmental period in the water, the eggs hatch into free-swimming larvae (*coracidia*), which to continue development must be eaten by a copepod. The parasites penetrate the intestinal wall and so reach the body cavity of this host, where they develop until the copepod is in turn eaten by a fish, when they usually penetrate to the flesh of the host and grow to approximately six millimeters in length. Various fishes, such as the northern pike, *Esox lucius*, wall-eyed pike, *Stizostedion vitreum*, sand pike, *S. canadense griseum*, as well as the burbot, *Lota maculosa*, may all serve as second intermediate hosts for this important parasite. Man and other carnivores acquire the infection by eating improperly cooked fish.

The bass tapeworm which matures in large- and small-mouthed black bass also requires three hosts — copepods, small fishes which carry the larval stage encysted in the viscera, and the final host, or adult bass. The life cycle of this parasite illustrates very clearly the interdependence of organisms necessary for the completion of the



N. Y. State Conservation Dept.

Diagram of the life cycle of the yellow grub of bass (*C. marginatum*). (1) The adult fluke in buccal cavity. (2-4) Embryo within egg hatches as free living miracidium which, upon entering snail, produces a mother sporocyst and two generations of rediae (5-8), cercariae (8-9), liberated by the daughter redia, penetrate many species of fish (10-11) and mature when eaten by various herons (12).

cycle. The adult tapeworm matures sexually in the spring of the year, the mature eggs being shed into shallow water where the fishes come inshore to spawn. The eggs of the parasites are soon eaten by copepods and the developmental period necessary for the larval parasite to reach its second infective stage is closely correlated with the time interval between the laying of the bass eggs and the absorption of the yolk sac of the bass fry. At the time the young fishes begin feeding upon plankton, the copepods in the vicinity of bass nests are found to be much more heavily parasitized than at other seasons of the year. It is adaptations such as these which enable parasites to complete complex life cycles.

Flukes, or trematodes, probably undergo more complicated cycles than any other group of parasites. In considering the complex cycle of a trematode one should keep in mind that there are usually

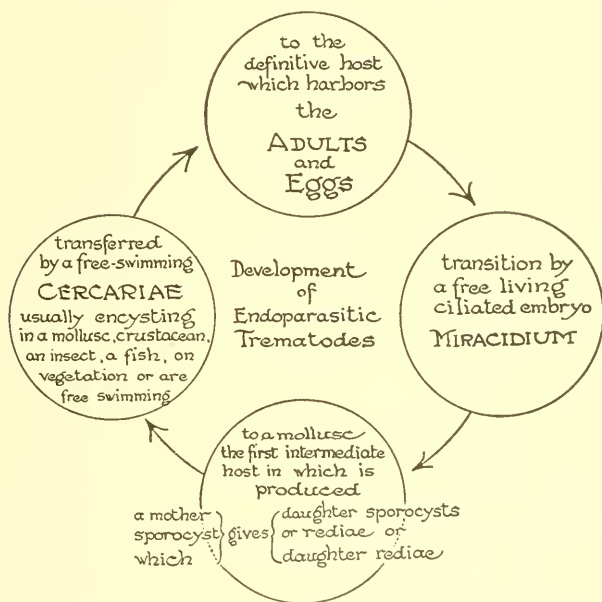


Diagram explaining the life cycle of endoparasitic trematodes.

two free-living stages, — the *miracidium* and the *cercaria*. The variations that may be expected in such a cycle are apparent upon inspecting the above diagram.

The frequent presence of a second intermediate host suggests a characteristic of most trematodes. For example, the great blue

heron harbors an adult fluke, *Clinostomum marginatum*, in its mouth cavity. Eggs discharged by the parasite reach the water and soon hatch, the *miracidia* penetrating snails. After several generations in the snail, fork-tailed *cercariae* emerge to penetrate under the scales into the flesh and sometimes on the fins of many species of fresh-water fish. Here they grow into the typical yellow grubs commonly found surrounded by a cyst formed by the connective tissue of the host.

As a result of the above discussion of parasitism it is hoped that some concept of the elaborate food chains and interrelationships and interdependence characteristic of the various groups of parasites and their hosts may be gained. Because these relationships are so complicated and form so intricately woven a pattern, it becomes practically impossible "to predict the precise effects of twitching one thread in the fabric."

SUGGESTED READINGS

Cowdry, E. V., et al., *Human Biology and Racial Welfare*, P. B. Hoeber, 1930. Ch. XVII.

Popular discussion, resistance, etc., from the bacteriological point of view.

Elton, C., *Animal Ecology*, The Macmillan Co., 1935. Chs. V, VI.

Excellent readable discussion of parasitism from an ecological viewpoint.

Massee, George, *Diseases of Cultivated Plants and Trees*, The Macmillan Co., 1910, pp. 1-23, 59-77.

A good discussion of parasitic plants.

Needham, J. G., Frost, S. W., Tothill, B., *Leaf-Mining Insects*, The Williams & Wilkins Co., 1928. Ch. I.

Deals with natural history of group.

Smith, T., *Parasitism and Disease*, Princeton University Press, 1934.

Excellent general, but somewhat technical, discussion of the parasitic habit.

XIII

ADVANTAGES OF BEING A VERTEBRATE

PREVIEW. Vertebrate characteristics · Skeletons · Invertebrate attempts · The vertebrate endoskeleton · Suggested readings.

PREVIEW

How fortunate it is that we are vertebrates, not only vertebrates in general but mammalian vertebrates of the royal *primate* line which has blossomed finally into human beings!

When one thinks over the myriads of lowly, less endowed animals scattered along the devious highways of evolution, who might have been our near relatives, it is a real privilege to claim relationship with such highly endowed primates as monkeys and apes. With the inclusive vertebrate type, to say nothing of the specialized *Primates*, there are certain outstanding structures and qualities which we as mankind are thankful to possess. They are so familiar to us, however, that we are apt to forget how far our fortunate biological heritage is dependent upon them.

Only a few of these distinctive vertebrate characteristics that give us occasion for self-congratulation may be pointed out here. A consideration of the VERTEBRATES as such forms a biological science in itself, set forth in a voluminous library of descriptive and interpretative books.

Vertebrate Characteristics

Even a partial list of the distinctive vertebrate endowments would include the following: 1, a highly developed *nervous system*, based upon a hollow dorsally-located nerve cord; 2, a unique embryonic skeletal axis, called the *notochord*, which is the foundation for a *living internal skeleton*, adaptable to the changing demands of growth; 3, a peculiar kind of *blood*, that in the higher forms makes the maintenance of a constant body temperature possible regardless of the surrounding temperature; 4, various devices for effectually *transporting the blood* to every part of the body, devices that are as superior to the methods employed by non-vertebrates as modern highways and means of transportation are better than the conditions encountered in the days of the trackless wilderness; and 5, *locomotor organs* for

getting about on land, in water, and in air, far surpassing those employed by lower animals.

Skeletons

Let us consider briefly just one vertebrate feature, namely, the *living inside skeleton*, which gives the name "vertebrate" to the group. It is the culmination of an endless array of experiments and adaptations that have been going on since the beginnings of life on this planet, and there is every indication that the end is not yet. The skeleton of man, for example, is by no means the final mechanism of its kind. There are to be expected in the future other models nearer to perfection, though based upon all that has gone before.

Invertebrate Attempts

The microscopic protozoa made brave experiments with the idea of a skeleton, in their case an armor mostly for protective purposes and consequently found located on the outside of the animal itself. In fact, *protection* seems to be the primary service of skeletal structures in general, although secondarily supplanted largely by the function of *support* and *muscle attachment*. It still plays an important rôle even in the vertebrates, since the brain and cord, being extremely liable to injury, are enclosed within a protective skull and enveloping vertebral arches, while the viscera are in part stowed away within a bony thoracic basket.

In the great group of arthropods, that includes both crustaceans and insects, the skeleton is plainly a protective external covering which, being a lifeless excretion of the skin, does not change in size after it has been laid down. As the animal grows, the dead inelastic skeletal armor thus formed fits more and more tightly over the enlarging body until finally it has to crack open in order that the animal may emerge and become refitted, after an interval of rapid bodily expansion, with a new and larger skeletal garment. This complicated process is called *molting*. To elaborate and then periodically to reject all this material is not only a physiologically expensive performance but it is also a hazardous one, since while shifting into a more commodious suit of armor, the animal may lose a leg or two, and is always exposed for some time to enemies while in its defenseless shell-less condition.

Insects, caught in the same evolutionary blind alley with their crustacean cousins, have taken an upward step by secreting a much

thinner chitinous envelope than the more cumbersome "crust" of the crustaceans. Instead of molting at repeated intervals throughout life, they have hit upon the idea of *metamorphosis*, whereby they do all their molting early during the growing larval stages. Then, as adults of established and unchanging size, they live happily ever after without being troubled by the inconveniences and perils of growth within an unadaptive external encasement.

Another and paramount objection to a protective exoskeleton is the increasing burden of a heavy armor which soon becomes insupportable, necessitating a limit to the size of the body encased within it. The largest known representative of the enormous group of the insects is probably smaller even than the smallest adult vertebrate.

The molluscs have gone at the problem of evolving a skeleton in another way. Although the skeleton is still on the outside, excreted and consequently lifeless, it is never wastefully molted after the crustacean fashion. The parsimonious molluscs keep every particle of their old dead shells and simply add new layers on the inside, as growth demands. The layers, being a little more extensive with each addition, form by their edges the familiar "lines of growth" showing as parallel ridges on the outside of the shell. This particular experiment in skeletons, however, has cost the group of molluscs dear, for the heavy shell, together with the accompanying policy of passive defense, has either impeded the power of locomotion with all attendant advantages that would accrue for the evolution of the nervous system, or has brought about its complete abandonment. The clams and their allies, therefore, have stuck conservatively in the mud and lagged behind in the race for life, while other animals without the incubus of a molluscan shell have toiled successfully on to higher levels of attainment in working out their organic salvation.

The Vertebrate Endoskeleton

The vertebrates alone exploit a fundamentally different model in skeletal structure.

An increase in size being necessary for dominance in the struggle for existence, an adequate supporting *scaffolding* for the body is demanded, and as a result the skeletal function of protection now becomes secondary. *Levers* and muscles to work them to attain locomotion, with ample *skeletal surface for their attachment*, are also indispensable for animals that are to develop a successful nervous system. The vertebrate skeleton provides for these adaptive advances.

The fact that the vertebrate skeleton is inside the body makes it a changeable living structure which, by reason of its capacity for continuous growth, keeps pace with the increasing demands of the enlarging organism. With the introduction of such a scheme of mechanical support, the ban upon size imposed by a lifeless exoskeleton is lifted, so that during the Age of Mesozoic monsters there were dinosaurs and similar beasts, for example, that were able to lift tons of flesh into the air upon majestic bony scaffoldings. These prehistoric giants proved impracticably large, however, and vanished forever from the face of the earth after recording by means of their fossil remains the results of these colossal experiments in the mechanism of living inside skeletons. There still remain today, elephants on land and whales in water as living illustrations of how far it is possible to go in the matter of size when an adequate living internal support is provided.

The remarkable superiority of the vertebrate endoskeleton over all other skeletal devices is evident. It would be possible to go much further and to unfold some of the marvelous details of adaptation which every separate part of the vertebrate skeleton presents. That would call for many pages. It is the task of the comparative anatomist to assemble and elucidate the innumerable facts about the vertebrate plan of structure, of which those involved in the skeleton are a sample, and to point out wherein we are fortunate to be constructed as we are. This is a fertile field, inviting intellectual adventure for those who have the curiosity to explore it.

SUGGESTED READINGS

Adams, L. A., *An Introduction to the Vertebrates*, John Wiley & Sons, Inc., 1933.

A fine text.

Keith, Sir A., *The Engines of the Human Body*, J. B. Lippincott Co., 1919.

Parallels intriguingly worked out for the mechanically minded.

Neal, H. V., and Rand, H. W. *Comparative Anatomy*, P. Blakiston's Son and Co., 1936.

Written by two masters of the subject.

Newman, H. H., *Vertebrate Zoology*, The Macmillan Co., 1920.

Just what the title indicates.

Walter, H. E., *Biology of the Vertebrates*, The Macmillan Co., 1928.

Many illustrations. Bibliography.

Wilder, H. H., *History of the Human Body*, Henry Holt & Co., 1923.

Told with literary grace without sacrifice to accuracy.

THE MAINTENANCE OF THE INDIVIDUAL

XIV

THE RÔLE OF GREEN PLANTS

PREVIEW. Structure of green plants · The raw food materials used by plants · The root and its work · The stem, structure and function · The structure of the leaf · How green plants make food; carbon dioxide as raw material; the rôle of water; chlorophyll and light; relation of artificial light to food making; what goes on in the green leaf in sunlight; chemistry of food making · Enzymes and their work · How food is used by the plant body · Respiration · Transpiration · The rise of water in plants · Production of oxygen by plants · Suggested readings.

PREVIEW

It is a trite statement to say that the destiny of man on the earth depends upon green plants. All living stuff is made up of the elements found in air, in water, and under the earth's surface, yet no laboratory technician has ever been able to put this material together and make protoplasm. That energy is displayed by plants and animals is obvious, but no man has ever been able to energize matter and create a living organism. We know that the units of structure, the cells, do release energy and that this energy comes, as does all other energy, from the oxidation of fuel substances. Such fuels used by living things we call foods. Moreover, these foods, be they from plant or animal, in the long run depend upon energy derived from the sun. The Biblical declaration that "all flesh is grass" is literally true, for without green plants animals would have no food.

We do not think of plants as very dynamic objects compared with animals. Nevertheless, if we look at the soil pushed up by growing seeds, the pavement broken by the growth of trees, and even the hardest rocks split apart by the wedge action of growing stems and roots, we realize that plants are very much alive. They respond to the various stimuli in the environment, reacting like animals to temperature changes, to gravity, to various chemical substances, or to the directive force of currents of water.

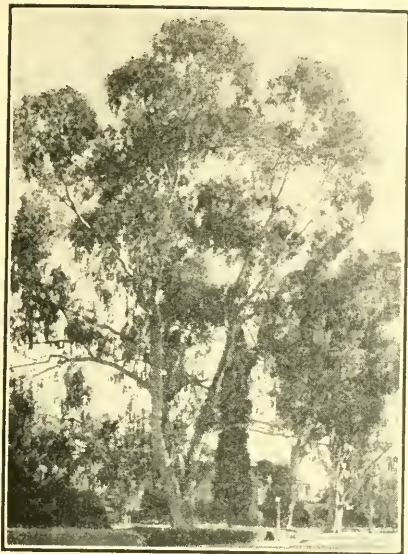
Unlike animals, whose metabolism is catabolic, the green plant's metabolism is more completely anabolic. It builds up materials to

a greater extent than it tears them down in the metabolic process. Compare the growth of an animal with that of a plant such as a big tree. While the animal is more fixed in size and limited in age, the tree grows for a longer period of time and grows to a greater size. These differences are due to a continuous growth of the meristemic tissue already mentioned, and also to the fact that new tissues and organs grow continuously from this area of meristem that is found in growing buds, stems, and roots. The most important difference between green plants and animals lies in the fact that the green plant can make use of the sun's energy to manufacture foodstuffs on which not only it, but also the animals which eat it, depend.

In an investigation of a living green plant, two methods of study present themselves. We can rather carefully dissect and study each system of structures which makes up the living organism and direct our attention to the microscopic make-up of each part. In this way a fairly complete picture will be had of the organism in its entirety. But such a picture will lack vitality. If the plant is a living thing, then why not study it from the point of view of function, of what it does and how it lives, using only so much reference to the structures as will make intelligible the work of the parts of the plant? This is the viewpoint adopted for this unit. The plant is to be thought of as a living, working organism, performing the same metabolic functions as any other organism, but in addition doing a different kind of work from that of animals, that of synthesizing organic foodstuffs out of chemical raw materials from the air, the soil, and the absorbed water. This unit, then, will bring up a number of important points. Among them will be such questions as these: What are the adaptations which enable the green plant to do its work? Where does the raw material from which food is manufactured come from and how does the plant get it? Under what conditions is the work of food manufacture performed? Where is food made and how does it get to the cells where work is done? Why is light necessary for green plants and why do they bleach in the darkness? Are green plants really as important as is here indicated? These and similar questions will be answered in the pages that follow.

Structure of Green Plants

It is not easy to give a general description of a green plant. In the higher plants it is obvious that there are several well-defined regions which are called root, stem, leaves, flowers, and fruits. In these



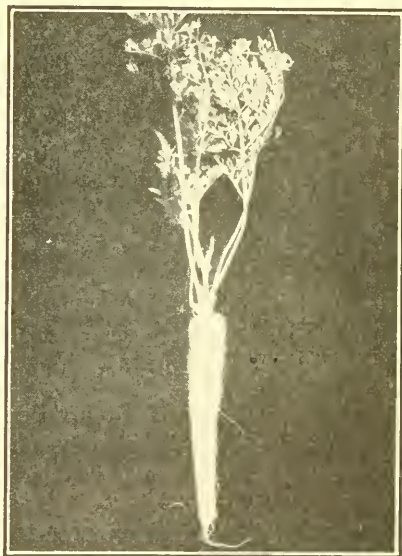
1



2



3



4

Wright Pierce

(1) Eucalyptus trees, natives of Australia, which have found California so well suited to their needs that they are a dominant form there. (2) Rose, shrub showing bushy habit. (3) Snapdragon, a common annual. (4) Carrot, a biennial; note the food storage in the root. Of what value is this to the plant?

regions several different methods of growth occur which will be described later. Some plants that grow more or less continuously, forming a woody body which resists cold and storm, are called *trees* or *shrubs*. Others die down at the end of the year, although they have some wood fiber in the body. These are the *herbaceous plants*, examples of which are peas, beans, and a variety of garden plants and roadside weeds. Herbaceous plants that produce seeds and die before the following winter are called *annuals*.

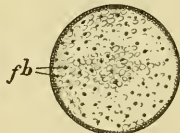
Dicotyledon Monocotyledon



Seed



Leaf



Stem

Differences between monocotyledons and dicotyledons; *c*, cotyledon; *e*, endosperm; *fb*, fibrovascular bundles; *h*, hypocotyl; *p*, plumule.

A second group of herbaceous plants, called *biennials*, store food in the roots or underground portion of the stem. After the upper part of such a plant is cut down by unfavorable weather conditions, the following spring the underground portions send up a new shoot from the subterranean food supply. This gives rise to flowers and seeds at the close of the second year. Examples of biennials are carrots, parsnips, and beets.

A third type of herbaceous plants is the *perennial*, which grows each spring from the underground parts that remain alive during the winter. Many of our common weeds have this habit, which makes them difficult to eradicate.

Woody plants, such as trees and shrubs, as we have seen in the

unit on classification, are grouped either as conifers (the softwoods, pines, firs, hemlocks, and their relatives) or as deciduous hardwoods. The latter are placed with the flowering plants, and may be either *monocotyledons* or *dicotyledons*. These two groups have differences in the structure of leaf, stem, and seed. The monocotyledons usually have parallel-veined leaves, like those of grass or lily. Their stems have scattered "closed" woody vascular bundles and a single cotyledon in the seed. The dicotyledons have netted-veined leaves,

such as are seen in the elm, oak, or sassafras; stems with "open" vascular bundles which usually appear as a ring of growing tissue; and seeds with two cotyledons or seed leaves. These structures will be referred to in more detail later.

The Raw Food Materials Used by Plants

For a good many centuries after the time of the Greek philosophers who first held this theory, it was thought that green plants absorbed food from the soil, but it was not until the time of the Belgian philosopher van Helmont, who lived in the sixteenth century (1577-1644), that it was clear that water played a very important part in the growth of a plant. One of van Helmont's experiments consisted of placing a willow slip weighing five pounds in a vessel containing two hundred pounds of dried soil. For five years he watered the tree with distilled water, making careful observations on it until it had grown to be a sapling weighing one hundred and sixty-nine pounds and three ounces. But when he weighed the soil in which the tree had grown, he found it had lost only two ounces. Clearly then, the gain came largely from sources other than soil, and he rightly concluded that water was largely responsible for the increase in weight. In the first half of the eighteenth century, an English clergyman, Stephen Hales, worked out the daily water consumption of a plant by ascertaining the relation between leaf and stem surface and the quantity of water absorbed. He went a step further than van Helmont in suggesting that plants take something from the air as well as the soil with which to build up their body material. In 1779, Ingen-Housz, a Dutch physician, who was a co-worker with the famous surgeon, John Hunter, showed that the green part of a plant, when exposed to light, uses the free carbon dioxide of the atmosphere, but that it does not have this power when kept in darkness. A little later, in 1804, de Saussure, by a series of experiments, proved that carbon dioxide and water were both used by plants in the sunlight and that as carbon dioxide was taken from the atmosphere, about the same amount of oxygen was returned to it. He, however, missed the use of the green coloring matter of the leaf in its connection with the sun's energy in building living matter and food. The real explanation of the function of this green substance (*chlorophyll*) was left for Julius von Sachs, a famous botanist of the nineteenth century. He was the first investigator to demonstrate the fact that green plants make food for the world. Just how they do this is still not fully known, although plant physiologists

have been experimenting and are still experimenting in the attempt to solve the problem.

With this background, our point of view is to consider the living green plant as an organism, faced by the same kinds of problems as a living animal, taking a living from its environment, storing up food for the inevitable time of food shortage, and eventually forming fruits to hold the seeds which are necessary to pass the stream of life on to the next generation. Unlike an animal, the green plant takes raw food materials from its environment and, under certain favorable conditions, synthesizes them into organic foods, a process effected by means of a number of adaptive structures, in certain favorable environmental conditions, the chief of which is sunlight.

By burning the body of a living plant until nothing but ash remains, and then making a careful analysis of this residue, frequently as many as thirty chemical elements are found. Twelve are nearly always present, eight of which are essential to plant growth. The latter are boron, calcium, iron, magnesium, manganese, phosphorus, potassium, and sulphur. It will be noticed that this list does not agree exactly with the previous list of elements usually found in the protoplasm of living things (page 131), but the implication is clear. The chemical elements found in living matter, as previously noted, are also found in rocks or soil, air, and water. The stage is set and it remains for the scientist to discover just how these elements, found in the environment, can be made into food and living stuff by the green plant.

A good many experiments have been made with plants to determine more exactly the function of these elements. It has been shown that if green plants are placed in a nutrient solution containing the necessary elements,¹ growth will take place. If, however, certain elements are subtracted from the solution, the plants will not develop, or their growth will be considerably slowed down. Such experiments give us our first clue to one important use of the root. It is evidently an absorbing organ through which the plant takes in not only water, but some of the essential mineral materials necessary for its growth.

¹ A list of the most commonly used nutrient solutions for plant growth are given below.

Crone's solution: Water, 2.0 l.; KNO_3 , 1.0 g.; FePO_4 , 0.5 g.; CaSO_4 , 0.25 g.; MgSO_4 , 0.25 g.

Detmer's solution: Water, 1000 g.; $\text{Ca}(\text{NO}_3)_2$, 1.0 g.; KCl , 0.25 g.; MgSO_4 , 0.25 g.; KH_2PO_4 , 0.25 g.; FeCl_3 , trace.

Knop's solution: Water, 1000 g.; $\text{Ca}(\text{NO}_3)_2$, 1.0 g.; KNO_3 , 0.25 g.; KH_2PO_4 , 0.25 g.; MgSO_4 , 0.25 g.; FePO_4 , trace.

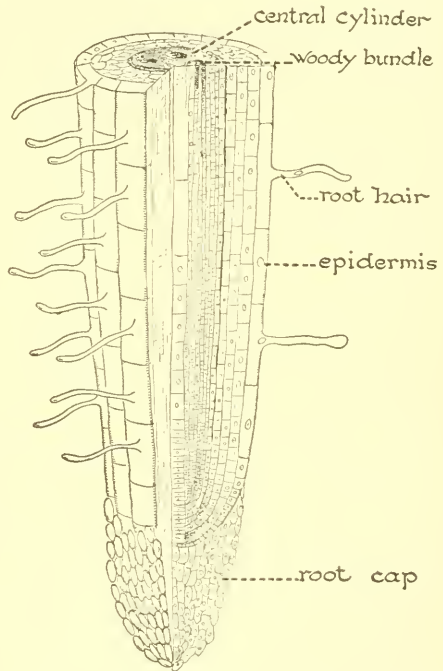
Pfeffer's solution: Water, 3-7 l.; $\text{Ca}(\text{NO}_3)_2$, 4 g.; KNO_3 , 1 g.; MgSO_4 , 1 g.; KH_2PO_4 , 1 g.; KCl , 0.5 g.; FeCl_3 , trace.

Sachs's solution: Water, 1000 g.; KNO_3 , 1.00 g.; NaCl , 0.50 g.; CaSO_4 , 0.50 g.; MgSO_4 , 0.50 g.; $\text{Ca}_3(\text{PO}_4)_2$, 0.50 g.; FeCl_3 , 0.005 g.

The Root and Its Work

Recent experiments made by Weaver¹ and others show that plants have extremely complicated root systems. The roots of an old oat plant, for example, although extending through only about two cubic yards of soil, were found to have a total length of over 450 feet. Weaver found that hardy wheat plants sent their rootlets into the soil six feet below the surface of the ground. In the bush morning-glory, a common plant of the mid-western plains, the roots may extend ten feet into the ground and a distance of twenty-five feet away from the parent plant. The roots of corn extend laterally three to four feet from the stem and sometimes over seven feet into the soil. All this is evidence for the great importance of the root as an absorbing organ.

Examination of longitudinal sections cut from growing roots shows that the body of a root is made up of a central woody cylinder surrounded by layers of softer cells, collectively called the *cortex*. Over the lower end of the root is found a collection of cells, most of which are dead, arranged in the form of a cap covering the growing tip. As the root pushes through the soil, the outer cells of this root cap are sloughed off, and are rapidly replaced by growing cells of *meristem* that are just under the root cap. The root cap proper is evidently a protective adaptation. In the woody region of the root are vascular tissues consisting of *xylem* and *phloem*. These tissues form a series of tubelike structures which together with



Root of a dicotyledon, greatly magnified. Find the functions of each part labeled. How might soil water get from the outside of the plant into the woody bundles?

¹ Weaver, *Root Development of Field Crops*, McGraw-Hill Book Co.

strong supporting woody cells constitute the vascular bundles that put the root in connection with the stem and leaves above it.

If mustard seeds, for example, are germinated in a moist chamber, a few days after germination the lower part of the root will be found to be covered with a delicate, fuzzy growth. Examination of the root at this stage shows an actively growing area of meristem, an elongating zone of tissue directly back of it, with a zone of maturing tissue above, which together make a zone of growth coinciding more or less directly with an area covered with fuzzy structures known as the *root hairs*.



Root hairs of corn, showing their relation to the root tip.

Root hairs vary in length according to their position on the root, the longer ones being found at some distance from the tip. They are outgrowths of the outer layer of epidermis. A single root hair examined under the compound microscope is found to be a threadlike, almost colorless structure. The delicate cellulose wall is lined by the protoplasm of the cell, the outer layer of which forms a selectively permeable membrane. Inside the root hair are found numerous vacuoles filled with cell sap. A nucleus is always present and may be found in the basal part of the cell, or in the hairlike portion itself. The root hairs are evidently living epidermal cells.

An examination of a young plant growing in moist soil shows that the root hairs reach out between the particles of soil, apparently being closely cemented or attached in places to them. Each particle of soil is surrounded by a delicate film of water, which, with the dissolved minerals found in it, is absorbed into the root hair by the process of osmosis. The wall of the root hair is covered with a delicate layer of mucilagelike *pecten* formed by the outer layer of the cell wall and is also in contact with the moist protoplasm within the cell, which forms a delicate membrane



Root hair, showing its relation to an epidermal cell. How do you account for the attachment of the soil particles to the surface of the root hair?

just under the wall. Diffusion takes place following the laws of osmosis, according to which water passes through a selectively permeable membrane from a point of its greater to a point of its lesser concentration. This means that water passes from the soil into the cell sap, which has a higher concentration of solutes than does the water. Since the cell sap within the root hair has received a greater quantity of water, it in turn becomes a point of higher concentration of water than the cells lying next to it interiorly, and consequently, the flow continues from these outer cells to the adjoining cells which have a higher concentration of solutes. In this manner water is passed through the cells of the root into the woody cylinder inside the cortex. Once having reached this region it passes up the tubes into the stem and on into the leaves as will be shown later.

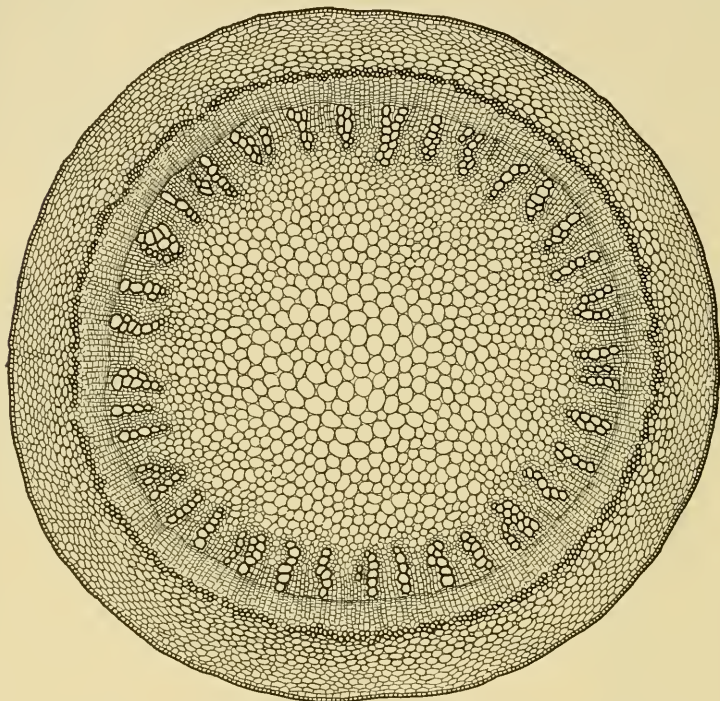
The Stem, Structure and Functions

In thinking of the tree as a living organism, we are not so much concerned with the internal structure of the stem as with the way it functions. For many centuries it has been known that water passes up through the wood. If a tree is girdled — that is, if a narrow strip of bark extending inward as far as the wood is removed — the tree will keep its leaves for some time, indicating the upward passage of water which keeps them from wilting. If, however, a strip of wood directly under the bark is removed, enough of the bark being left intact to allow for passage of fluids, the leaves will wilt within a very few moments. A cut branch of apple or willow placed in red ink after a few hours shows by a red circle, visible in sections cut across the stem, that the colored water has passed up through the outer layers of the new wood.

In order to understand better the pathways for the rise of sap in the dicotyledon stem, one must study its growth. When seen in cross section, the vascular tissues of such stems are arranged in a circle. In some herbaceous stems, the woody bundles are separated by a *parenchyma*, but in trees, shrubs, and a good many herbs, the bundles are united to form a complete ring around the stem. These vascular bundles are open at each side and grow more or less continuously from a single row of meristem or embryonic cells which form a layer around the stem. This layer is called the *cambium*, and the growth of the wood and bark of our large trees is due to the activity of this always youthful layer of cells which, like the cells of embryonic tissue, continually divide and multiply to form internally the *xylem* or wood

and externally the *phloem* tissue. In the spring when this tissue is very active, it forms a soft layer of cells that allows of the easy separation of bark from wood, a fact well known to any small boy who has made a willow whistle.

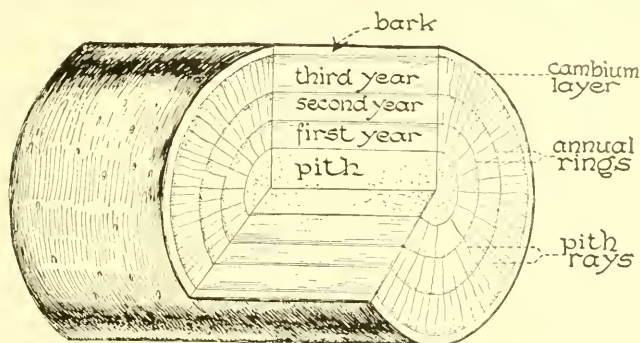
It is not necessary to go into the details of stem structure, except to note that the cambium layer gives rise each year to new layers of



Cross section of stem of *Ricinus communis*, a dicotyledon, showing cambium ring. In what area of the diagram does growth take place ?

tissues, both internally and externally. The inner layers made up of secondary xylem are from the *annual rings* of a tree. In spring the growth of the tissue is rapid, while in winter it is very slow indeed or stops entirely, thus making the differences in the cross section shown in the figure. As the tree ages, changes may be noticed in the appearance of the older woody area forming the interior of the trunk. This wood becomes darker in color, its chemical composition changes, and it loses its ability to conduct water. It is known as the heart-wood as distinguished from the outer rings of wood called sap-wood.

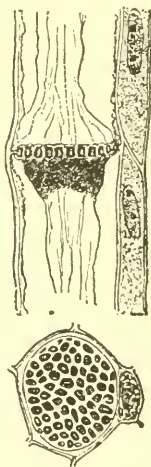
The latter conducts water, while the heart-wood functions merely as a supporting tissue. As the tree increases in diameter, the area of



Section through a dicotyledonous stem. Explain its method of growth.

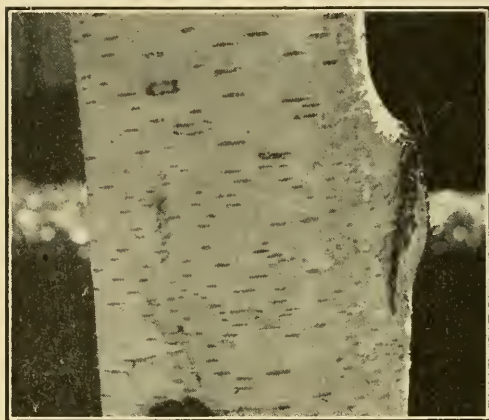
heart-wood increases while the sap-wood, although greater in circumference, gets proportionately smaller in extent.

The *bark*, or area outside the cambium, is made up of several different tissues, which have a somewhat different arrangement in conifers than in deciduous trees. The area known as phloem is formed immediately outside the cambium. This area contains many living *sieve tubes* through which elaborated food is carried down from the upper part of the plant. The sieve tubes in the conifers are more or less regular in arrangement while in deciduous trees they are scattered. In both stems they are all surrounded by parenchyma. Scattered through the bark of deciduous trees are masses of tough, stringy *schlerenchyma* cells of two types, phloem fibers — fibrous, elongated cells that give strength and elasticity to the trunk — and thick-walled, hard *stone* cells. Outside the latter area is formed the corky layer, produced by a layer of growing cells known as the *cork cambium*. Cork cells, which have their walls impregnated with an insulating substance called *suberin*, are of great value to the tree because they prevent a rapid loss of water from the tissues. It is this layer in the Spanish cork oak which is of commercial value. In some trees, such as the redwoods, the bark forms a coating highly resistant to fire.



Above, sieve vessel (of phloem) with companion cell; below, sieve plate, with section of companion cell. (After Strasburger.)

Scattered over the surface of twigs and young tree trunks are found many *lenticels*, openings in the corky layer which become filled



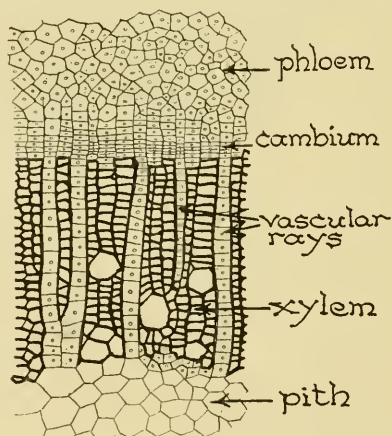
Wright Pierce

The characteristic lenticels of the white birch (*Betula populifolia*). Note the placement of the lenticles.

with loose masses of cells. They are found both on roots and stems and act as pores which allow for the exchange of gases between the living cells of the cortex and the medium outside. Lenticels are often spoken of as "breathing pores" and experimental evidence seems to make this title valid.

water and foods. Cells cannot grow without food, and food in a growing plant cannot be made without water. The structures which

put the water-conducting tissue of the inside of the stem in connection with the phloem of its outer part are known as *vascular rays*. They may be seen in almost any cross section of a tree which has produced secondary xylem and phloem. Here the cambium has rows of irregularly placed cells that instead of forming xylem and phloem produce ingrowing masses of more uniform parenchymatous cells making vertically placed strings of tissue. These bands



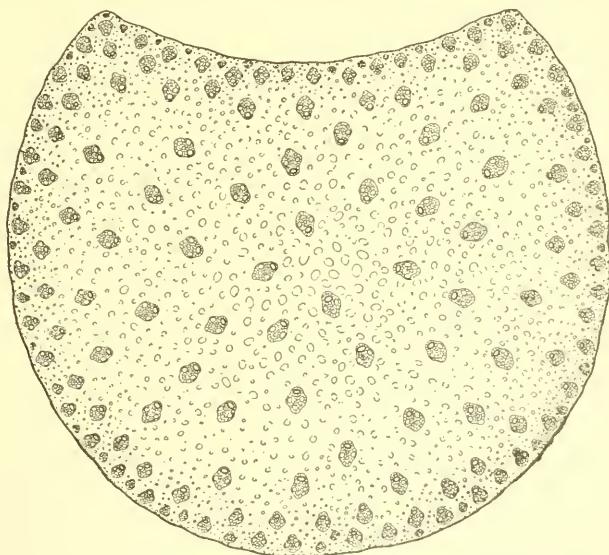
Note the bands of living parenchymatous tissue that grow inward toward the pith.

act as conducting pathways for water from the xylem to the phloem and also as channels for elaborated food from the phloem to the xylem, thus distributing these materials to the growing trunk. Experiments by

Auchter¹ have shown that food and water are not transferred from one side of a tree to the other, but instead that almost all of the water taken in is used directly above where it is absorbed, while food passes down from the leaves on the same side of the tree. There is seemingly little cross transfer of food or water in a plant stem.

Vascular rays must not be confused with the so-called *pith rays* which are formed in herbaceous stems such as *Ranunculus* or in the stem of *Clematis* where, as the primary wood bundles grow in the pith, the pith forms narrow plates between the bundles. These appear as the pith rays in a cross section.

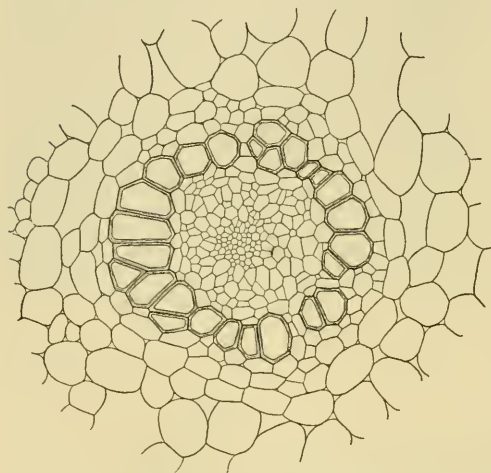
Conditions of growth upon which the passage of food and water depend differ in monocotyledons from those in dicotyledons. If a stalk of celery or asparagus is placed in red ink over night, the color is seen to be located in little fibrous bundles of tissue which are scattered throughout the stem. If such a stained stem is examined in cross section under the microscope, it is found to be made up of parenchyma or pith which is dotted with little groups of woody cells of irregular size and shape. These are the vascular bundles which,



Transverse section of stem of corn, a monocotyledon, showing the "scattered" vascular bundles which are cut in cross section.

¹ Auchter, E. C.: "Is There Normally a Cross Transfer of Foods, Water, and Mineral Nutrients in Woody Plants?" Univ. Maryland Agric. Exp. Station, Bull. 251, Sept. 1923.

instead of being located in a ring as in the dicotyledons, are scattered through the pith although more concentrated toward the outer edge of the stem. Examination of this outer edge or *rind* shows that there is no true bark, but that this outer area is made up of these same woody bundles closely massed together. Under high power, the bundles are seen to have outer strengthened walls of wood cells



A cross section through a closed monocotyledonous bundle. Note that the thick-walled xylem cells completely enclose the cells of the phloem.

enclosing tubelike cells of different diameters of which the larger have pitted surfaces. The area containing these tubes is the xylem. Other elongated tubular cells having their ends perforated with small holes like a sieve, form the sieve tubes, which are the conducting tissues of the phloem. In the phloem, the tubes pass foods down from the leaves, while the xylem carries water up from the roots to the leaves. The entire woody bundle is enclosed with a tough wall of

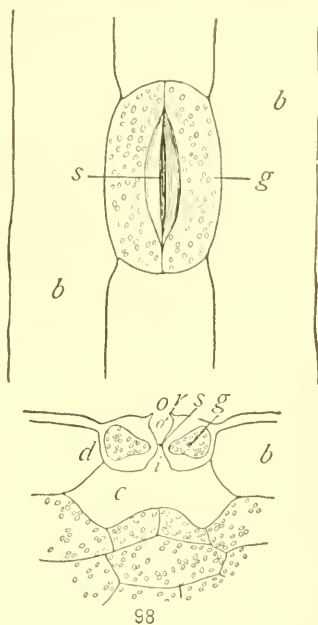
sclerenchyma which gives strength and resiliency to the stem. Since this hard tissue binds the entire bundle, it is called a *closed bundle*. Monocotyledonous stems grow, then, through an increase and lengthening of closed bundles in the parenchyma of the stem.

The end result in both monocotyledon and dicotyledon stems is the same. The vascular bundles put the root, stem, and leaves in direct communication. The root hairs at one end and the cells of the leaf at the other end are the opposite terminals of long communicating woody tubes. These tubes carry water and solutes up from the soil to the cells of the leaf, and, as will be shown presently, carry elaborated food materials down from the leaves to various parts of the plant, where they may be stored for future consumption or used immediately to liberate the energy needed in growth and in destructive metabolic changes. The vascular bundles which leave the stem to enter the leaves do so by way of the *petiole* or leaf stalk. As they enter the blade

of the leaf, they branch into bundles of ever smaller and smaller diameter to form the *veins* of the leaf. In the monocotyledonous leaves, these veins run in a more or less parallel direction as seen in grass blades or palm leaves. In the case of the dicotyledonous plants characteristic irregular and netted veins are found, reminding one of the branching of the capillaries in the human body. These veins are made up structurally of tracheids and tracheal vessels, serving as water-conducting tissues; sieve tubes, which carry out food materials from the leaf; and supporting tissue, which makes up the mechanical framework of the veins. Thus the veins act as a supporting skeleton for the leaf as well as conduits.

The Structure of the Leaf

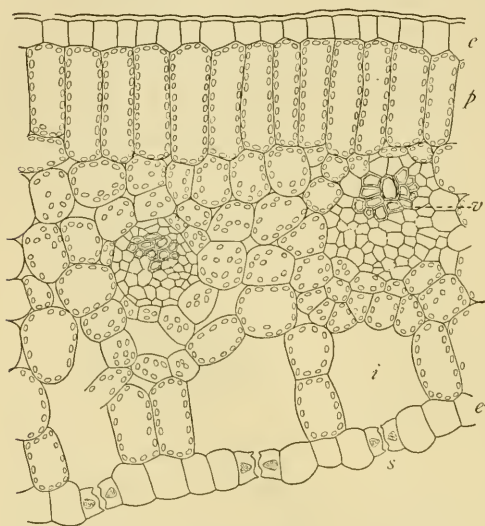
The outer covering of the leaf (*epidermis*) is composed of a layer of irregularly shaped cells, usually rather flattened. In some plants, like the mullein, these cells are prolonged into hairs, or again the layer, as a whole, is frequently covered with a waxy cuticle which is impermeable to gases and water. The under surface of the leaf, as seen through the compound microscope, shows many tiny oval openings, which are called *stomata*. The position of the stomata varies in different leaves. Some plants, as, for example, water lilies, whose leaves float on the surface of the water, have them in the upper epidermis. Others have them on the under side, and still others have them on both surfaces. The estimated number of these openings varies. MacDougal estimates that as many as two million are on the under surface of an



Stomata from the leaf of an Easter lily (*Lilium longiflorum*): Above, a stoma, as seen in surface view, showing the two kidney-shaped guard cells (*g*), which enclose the stomatal aperture (*s*), the more deeply shaded portion representing the central slit; note the chloroplasts in the guard cells; (*b*) subsidiary cells. Below, a stoma, as seen in cross section; note the guard cell (*g*) next to the subsidiary cell (*b*); the outer slit (*o*) is enclosed between the cutinized outer guard-cell ridges (*r*), the enlarged area just below being the outer vestibule (*o'*); below the central slit (*s*) is the inner vestibule (*i*), which here opens directly into the cavity (*c*) underneath the stoma.

oak leaf of ordinary size, while four or five hundred thousand to a leaf is a common estimate. Surrounding the opening of each stoma are found two kidney-shaped cells, the *guard cells*, which can easily change their shape under certain conditions. They are of great importance in the life of the plant, since they control to a great extent the amount of moisture that may be lost from the leaf's surface. The guard cells are noticeably greener than the epidermal cells, the color being due to many tiny green *chloroplasts*.

If the leaf is cut in cross section and examined under the microscope, it will be found to be made up largely of a tissue known as *mesophyll*.



Cross section through a leaf; *e*, upper epidermis, *e'*, lower epidermis, showing stomata (*s*); *i*, intercellular spaces in the spongy parenchyma. Note the cross section of the vein (*v*). Why is the palisade layer (*p*) so placed?

Lying close to the epidermis are one or two layers of elongated cells with the long axis placed at right angles to the surface of the leaf. These layers of cells are collectively called the *palisade* layer. Each cell of this layer contains numerous chloroplasts which are found in the protoplasm close to the cell wall. It has been estimated that a square inch of a sunflower leaf contains as many as thirty million of these chloroplasts, which are most important structures in the plant so far as food making is concerned.

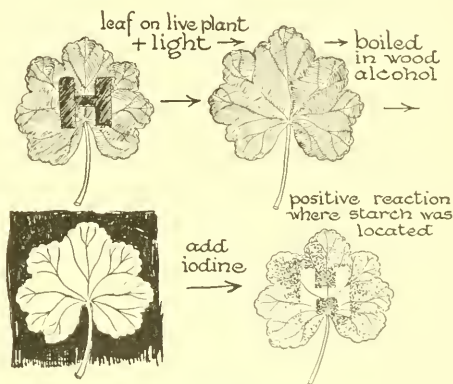
Below the palisade layer is a layer of numerous irregular cells containing fewer chloroplasts. These cells are known collectively as the *spongy parenchyma*. Between them are found air spaces connected with the exterior of the leaf through the stomata. We have already noted that the veins form the framework of the leaf and in a cross section are often found occupying part of the area of spongy parenchyma. These veins connect the vascular tissue of the root and stem with the leaf. The petiole, or leaf stalk, is made up largely of vascular and supporting

woody tissue. At one point on the petiole, usually close to the main stalk, a little time before the leaves drop from deciduous trees in the fall, a layer of delicate, thin-walled cells is formed which extends completely across the petiole. This is called the *separation* or *abscission* layer, and it is at this point that the leaf is cast off.

How Green Plants Make Food

The general biologist is concerned not so much with the structure of the organism or with detailed minutiae as with the general metabolism of an organism as a whole. He wants to know how plants and animals act as living things, both alone and in relation to each other. We have examined the green plant from the standpoint of structure and are ready to consider it as an organic whole, as a living organism that releases energy, respire, feeds, reproduces, and in time dies. But we must remember that in addition, the green plant *makes* food, and it is this process upon which we will now focus our attention.

It is a relatively simple matter to prove that sunlight is necessary for starch making in a leaf. Place a healthy green plant in darkness for a couple of days. Then pin strips of black



Proof that light is necessary for starch formation in green leaves.

cloth over parts of some of the leaves and expose the plant to bright sunlight for a few hours. Later, remove the leaves and boil them to soften the tissues, adding alcohol to extract the chlorophyll, and finally, place them in a solution of iodine. A blue color will appear in those parts of the leaves exposed to sunlight, while the covered areas will be colorless. The appearance of the blue color in the presence of iodine is the regular test for starch, thus showing clearly that sunlight is necessary for starch making.

Another simple experiment may be performed to show that air is also a necessary factor. Place a healthy green plant in darkness for two or three days, then carefully smear vaseline on the upper and lower surface of two or three leaves, leaving the others untouched.

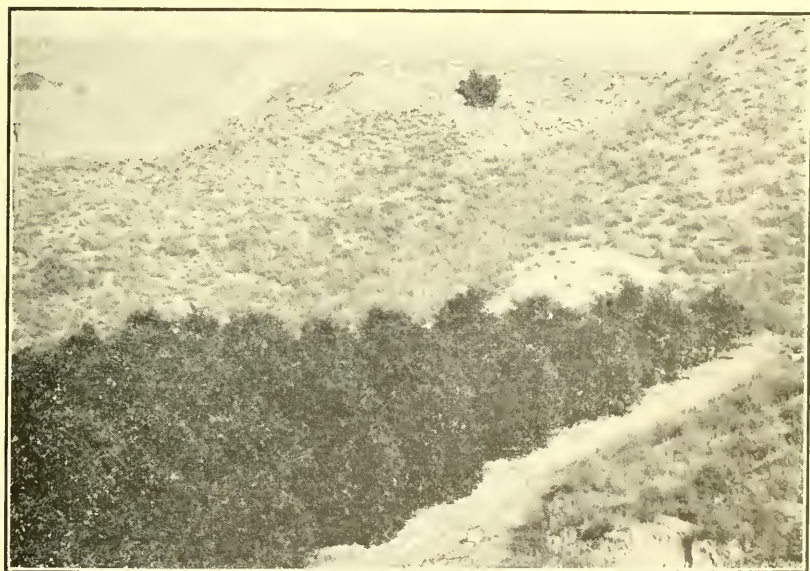
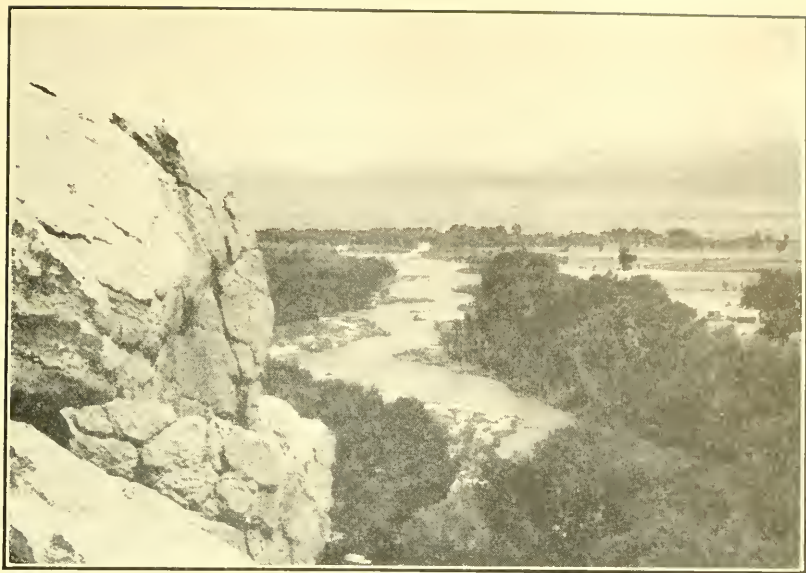
Place the plant in full sunlight for a few hours, then remove the vaselined and untouched leaves, and treat both in the manner described in the last experiment. The leaves to which no air penetrated will be shown to have no starch.

The need of carbon dioxide in the process of starch making may also be demonstrated by a relatively simple experiment. If plants are grown under similar conditions in two bell jars, but in one case the carbon dioxide in the atmosphere is removed by means of soda lime, while the other plant is left in the bell jar containing normal air, the latter continues to grow while the one lacking carbon dioxide does not increase in size.

By burning a plant in a hot flame, it can be ultimately reduced to mineral ash equaling about 4 to 5 per cent of the entire weight. According to Raber, from 1 to 55 per cent of the plant is consumed, while from 40 to 95 per cent, roughly speaking, consists of water. Since a green plant is immobile and since it has no way of obtaining material except from the air, water, and the soil that surrounds it, it may be safely assumed that if food is found in the plant body, it must be made there. That foods are found in plants is common knowledge. We eat roots, stems, fruits, and leaves of plants. Grains form our staples of food. Roots and various types of fruits form part of our dietary, while herbivorous animals live upon grasses and fodder crops. This brings us then to the sources of the raw materials out of which these elaborated foods must be formed.

Carbon Dioxide as Raw Material

Carbon dioxide is not only a product of respiration of animals but of plants as well. A man gives off about nine hundred grams of carbon dioxide daily into the air. Carbon dioxide also gets into the air from the combustion of inflammable materials. Volcanic eruptions and other sources of combustion increase the amount, while decaying organisms and the oxidation of rocks and soils add a very appreciable amount daily to the store. While it is estimated that there are only two grams of carbon in each ten liters of air, nevertheless the fact that carbon dioxide is universally available in the air and oceans close to the surface of the earth shows that it may readily be made use of by growing plants. Its need in food manufacture is well illustrated by the statement that the world crop of wheat requires annually one hundred and fourteen million tons of carbon dioxide in order to produce the seventy million tons of carbohydrates which form this crop.



Wright Pierce

The rôle of water. Upper photograph: The Mohave River near Victorville. This river rises in the San Bernardino Mountains and loses itself in a desert sink. What effect does it have upon the desert?

Lower photograph: An irrigated orange ranch in the desert near Claremont, California. Thousands of acres of trees now grow where desert conditions existed before irrigation.

The Rôle of Water

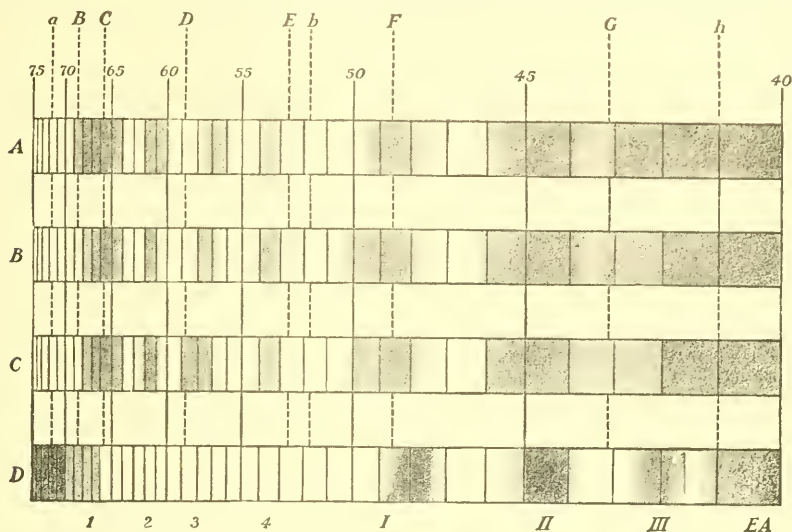
Water as a raw material needs little mention. The soil always contains more or less water, and the original source of water in its cycle through the oceans, the air, the clouds, and rain gives the earth a never ending water supply. When man aids Nature in carrying water to dry areas by irrigation the desert literally is made "to blossom as the rose." Certain chemical elements find their way into the plant body with this water. If the green plant is to manufacture organic food substances, it is evident that the elements carbon, oxygen, and hydrogen must come from the water and air. Various mineral salts, taken in by the root, furnish the necessary amounts of calcium, iron, potassium, sodium, and other elements, which leaves only nitrogen to be accounted for. Although nitrogen makes up approximately four fifths of the atmosphere, it is nevertheless unusable in that free form. It is an extremely inert gas and does not unite readily in combination with other substances. By means of the process of decay, however, and particularly through the nitrogen-fixing bacteria found on the roots of certain types of plants, this highly important element is made available to plants. So much for the raw materials. Now let us turn to the machinery of food manufacture.

Chlorophyll and Light

Common observation shows that there is a relation between light and the green color of plants. We are familiar with the bleaching of celery stalks, with the curious blanched elongated shoots of a potato which sprouts in darkness, and with the fact that young seedlings are devoid of chlorophyll until after they have sprouted. Seedlings grown with light coming from one side turn to the source of light, while plants grown in a dark box having a hole on one side work their way toward the light. Obviously light has a very potent effect on the plant.

Sunlight passed through a prism is broken up into seven primary colors ranging from violet to red, but passed through a spectroscope shows numerous dark lines traversing different areas in the spectroprism. The most conspicuous are used as landmarks by physicists and for convenience have been designated by the letters A to H by Fraunhofer, their discoverer. These several wave lengths of light can be measured and it has been found that they vary from 0.00076 mm. at the red end of the spectrum to 0.00039 mm. at the violet end.

Rays of greater and shorter length are also found at each end of the spectrum forming the ultraviolet and infrared portions. The heat of light rays varies, being greater at the red end of the spectrum. Since all life depends upon this radiant energy whose source is the

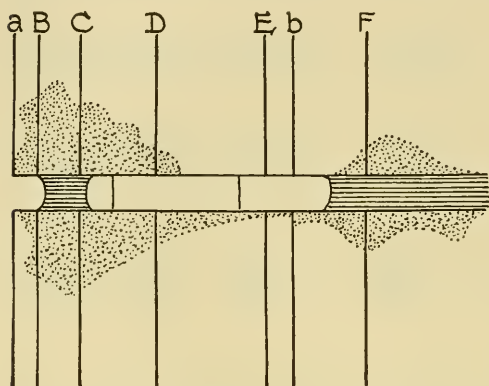


When a green leaf is placed in the path of light passing through a prism, dark strips appear, due to the partial or complete blocking of the light energy. These are shown in the absorption spectra above. A, chlorophyll of *Allium ursinum* in alcohol; B, chlorophyll of English ivy (*Hedera helix*) in alcohol; C, chlorophyll of *Oscillatoria* in alcohol; D, carotin. 1, 2, 3, 4, absorption bands of chlorophyll; I, II, III, absorption bands of carotin; EA, end absorption. The lettered broken lines mark the position of the principal absorption lines of the solar spectrum (Fraunhofer lines); the numbered solid lines form a scale from which wave lengths (λ) in millionths of a millimeter may be found by adding a cipher; note the increasing dispersion from left (red) to right (violet). (After Kohl.)

sun, the green plant is no exception to this rule. Certain parts of the plant, however, are more susceptible than other portions to radiant energy. While the green leaf as a whole needs sunlight, it is only chlorophyll in the chloroplasts that is able to utilize it for food making.

If a chloroplast is examined under a very high magnification of the microscope, it is found to be a mass of living matter somewhat denser than the protoplasm surrounding it. In its disk-shaped structure the green coloring matter is arranged around the outer part of the chloroplast, while the central portion usually contains a clear area

filled with fluid. Chlorophyll is a very complex protein, apparently made up of two substances known as Chlorophyll A, having the chemical formula $C_{55}H_{72}O_5N_4Mg$, and Chlorophyll B, $C_{55}H_{70}O_6N_4Mg$. It is found to be somewhat like the hemoglobin of the human blood except that it has an atom of magnesium instead of iron and the property of fluorescence, its color being different in transmitted or reflected light. Chlorophyll in solution, when extracted from the leaf by means of alcohol, appears green as light passes through it, but red when light is reflected from it against a black background. Other pigments are closely associated with chlorophyll, a group of yellow



Engelmann's experiment to show the areas in the spectrum most favorable for oxygen release in a green alga. The dots represent bacteria.

pigments called *carotins*, which give the yellow color to carrots and other fruits or vegetables, and *xanthophylls*, pigments that help give color to leaves in the fall.

Numerous experiments have been made to discover how chlorophyll does its work. It has been found that if light is passed through this substance and then broken up by a prism, that part of the light which is

absorbed by the chlorophyll may be detected by the presence of absorption bands in the spectrum where the chlorophyll has taken out the light. By this means we learn that the red band of the spectrum is most active while parts of the blue, violet, and indigo regions of the spectrum are also absorbed. A classic experiment by Engelmann illustrates this in another way. A filament of an alga was placed in a culture of bacteria which were active only in the presence of oxygen. The filament was then put in darkness until the bacteria had used up all the oxygen present. Then the slide containing filament and bacteria was placed on a microscope under a solar spectrum. In a short time the bacteria were found to mass themselves in abundance at the red end of the spectrum and to a lesser extent at the blue end, because at these points more oxygen was given off by the alga, thus indicating activity in starch formation.

Relation of Artificial Light to Food Making

We have already noted that there are great differences in the amount of sunlight required by plants. As a matter of fact, very strong sunlight may cause harm since it overheats the protoplasm, thus endangering the life of the plant. Moreover, it increases the rate of transpiration so that water is evaporated too rapidly. Experimental evidence with growing plants shows also that too much sunlight may retard growth. Some plants are shade loving, as may be



Shade loving plants on a forest floor. Note the leaf arrangement with reference to light.

seen in any field trip to a forest. The differences in illumination are correlated with differences in the structure of the leaf, the plants which are exposed to bright sunlight having a well developed palisade layer, while the spongy parenchyma is not so well developed. The reverse is true in shade-loving plants. In addition, plants that live in the shade are apt to have a very thin epidermis and usually have dull leaf surfaces which do not reflect the light as readily.

Contrary to common belief, it is possible to grow plants without sunlight as proved by recent experiments (Harvey) with a large number of different crop plants such as grains, tomatoes, squash, peas, potatoes, and others. Plants exposed continuously to the light

of nitrogen-filled tungsten lamps of from 200 to 1000 watts produced both viable fruits and seeds. The bearing of this experiment upon growing crops in areas where the days are short and the intensity of sunlight not great is readily seen. Lamps have been put on the market for use in the home which provide space directly underneath the bulb for stimulating plant growth during the winter season.

What Goes On in the Green Leaf in Sunlight

When we examine the green leaf to see how it is adapted to use the energy of sunlight, several interesting facts are discovered. One is that a plant places its leaves so that they get the largest possible amount of sunlight, in a given period. Petioles and even stems of plants turn with the sun so that a maximum amount of green surface is exposed to its rays. Looking at a tree from above as the bird sees

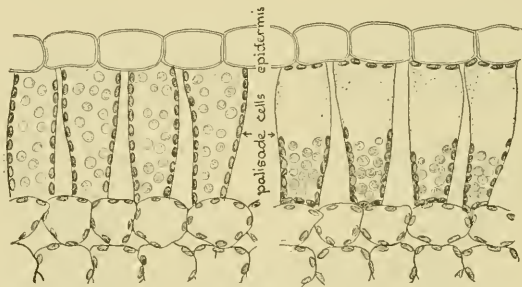


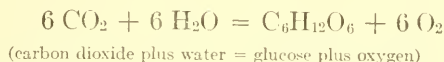
Diagram to show the cells of the palisade layer of a leaf at two different times during the day. Which of the two receives full sunlight ?

it, leaves are found to be so arranged that there is a minimum amount of overshadowing, the leaves forming a sort of mosaic or pavement on which the sunlight falls. Examination of the internal structure of the leaf also shows that the palisade layers which contain the greatest number of chloroplasts per cell are massed close under the upper part of the epidermis. It is this layer of palisade cells where most of the work of starch or sugar making takes place. In the cells themselves, the green chloroplasts are so placed that a maximum amount of light falls upon them. When the sun's rays are slanting during the morning and afternoon, light can reach all of them readily, while at the period of greatest illumination, when the sun's rays are direct, less light reaches them as they lie one above the other. Their position may be changed in the protoplasm, their movement being controlled by the

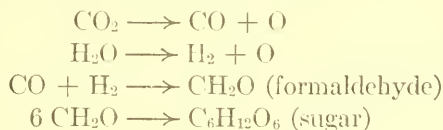
living substance in which they rest. The chloroplasts are the structures in the cells which utilize the sun's rays, and it is within them that the raw materials, carbon dioxide and water, are manufactured into sugar.

Chemistry of Food Making

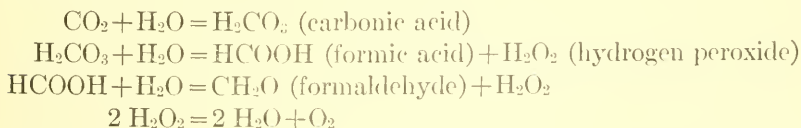
The actual processes of sugar and starch formation in the leaf are not fully known. The end process can easily be shown by the equation:



but how this glucose actually comes into existence is still problematical. Many theories have been advanced to account for the conversion of raw materials into foods. The one proposed by von Baeyer in 1870 is still accepted with modifications. He assumed that *formaldehyde* is formed by the breaking down of carbon dioxide into carbon monoxide and oxygen at the same time the water in the leaf is broken up into hydrogen and oxygen. The carbon monoxide and hydrogen unite to form formaldehyde, which is then built into glucose as shown by the following formula:

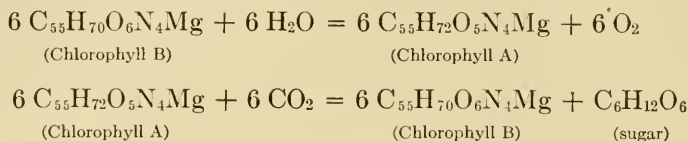


One objection to this theory is that carbon monoxide is extremely poisonous and is almost never found free in plants, while the product formaldehyde is also a poison. Later theories postulate that by first reducing carbon dioxide and water to carbonic acid, then to formic acid and hydrogen peroxide by the addition of a molecule of water, formaldehyde and hydrogen peroxide result, the peroxide being finally reduced to water and oxygen:



The last step in this process is brought about by an enzyme, known as *catalase*. Plant physiologists believe that although formaldehyde

is a poison, it is probably changed into sugar so rapidly that at no time is there much present in the cells of the leaf. The last part of this process, that of changing the formaldehyde to sugar, seems to be brought about by the action of the two chlorophylls, A and B. One recent writer, Gordon,¹ has given the following suggestive formula :



To the amateur chemist this means very little, but it suggests the double action of the two chlorophylls in the formation of sugar. All we really know is that sugar is first formed in the green leaf and that later this is changed to starch and stored in that form in various parts of the plant.

Of the manufacture of foods other than sugar very little is known. There are tiny droplets of fat in the vacuoles inside the chloroplasts. We know that fats can be synthesized out of carbohydrates by animals. Therefore, a similar process may take place in plants. Fatty tissue is undoubtedly manufactured out of the carbon, oxygen, and hydrogen contained in the sugar molecule. Probably a like situation exists in the chloroplasts of the leaves, although we do not know just how this process takes place.

Proteins are even more complex than carbohydrates and fats. Their molecule contains nitrogen and a number of mineral salts, in addition to carbon, oxygen, and hydrogen. Protein foods are found not only in leaves, but in most of the storage organs of the plant. Apparently proteins can be synthesized out of the sugar plus the elements nitrogen, sulphur, and phosphorus, which combine with the carbon, oxygen, and hydrogen of the glucose. Proteins are probably manufactured in other cells than those containing chlorophyll, wherever starches, sugar, and the essential salts are found, although light does not seem to be a necessary factor in the process. Proteins are undoubtedly used in any of the cells of the plant, just as they are in animal cells, for the making of protoplasm, since the plant is a living organism composed of cell units each of which is doing a common work for the plant as a whole.

¹ Gordon, R. B.: "Suggested Equation for the Photo-synthesis. Action." *Ohio Journal of Science*, 29: 131, 1929.

Enzymes and Their Work

The changes just described which take place in food making as well as in food storage, all belong to a series of oxidative and reducing changes that are presided over and brought about by enzyme action, another indication of the importance of these omnipresent substances.

We have already spoken of enzymes and their work, but reference to them again may not be amiss at this point. They are found practically everywhere in the living cells of plants and animals, being much more numerous than was at first believed. Although their nature is not fully known, we do know that they are colloidal substances, because they will pass through porcelain filter, but not through membranes. We also know that some of them are doubtless proteins, and that they are sensitive to light and ultraviolet rays as well as to heat, acid, alkali, and substances which are toxic to protoplasm. They are powerful *catalyzers*, as is shown by the fact that a single gram of the enzyme *invertase*, for example, will quickly hydrolyze one million times its weight of sugar. Enzymes are found in all living cells and are specific in action, that is, one enzyme will only do a certain type of work. In general, they may be divided into a number of groups, depending upon their function, such as the *hydrolases*, that act in the digestive processes of plants and animals by hydrolyzing materials; the *oxidases*, which enable cell respiration to take place; the *fermentases*, as, for example, *rennin*, that is used in cheese making, and the *coagulases*, to which *pectase* belongs that is used commercially in substances sold for use in jelly making; and finally, the *carboxylases*, which cause organic acids to split into carbon dioxide and other simpler substances.

Specific examples of these various plant enzymes include the enzyme, *diastase*, that causes the digestion of starch. Another enzyme, *maltase*, aids in the digestion of maltose to glucose, a still simpler sugar. A similar action takes place by means of the enzyme, *ptyalin*, in our own salivary digestion. Bacteria carry on a slightly different type of digestion in which cellulose or wood fiber is broken down and used as food. Here another enzyme, *cellulase*, causes this digestive change. Still another enzyme, called *lipase*, is instrumental in the digestion of fats. In fruits and seeds rich in fat, such as the avocado, Brazil nut, walnut, almond, or pecan, the fats are broken down into fatty acids and glycerine just as in animals where lipase is formed by the pancreas.

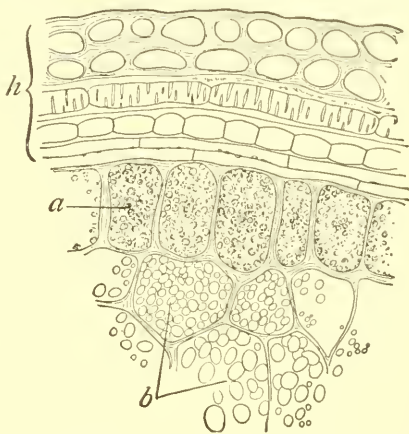
Protein digestion is brought about by a different group of enzymes, called *proteases*. These enzymes are found in abundance in leaves and germinating seeds of plants and to a lesser extent in practically all plant tissues. In the living plant, the digestive enzymes carry on a necessary and important work. If plants make foods in the green leaf, and they do, and if they store foods in the root, stem, fruit, and seed, then there must be some way to transfer the foods made in the leaf in a soluble form to those parts of the organisms where the food is finally used. This work of changing insoluble foods to soluble foods is obviously performed by enzymes. A still more interesting phenomenon sometimes takes place. Many of these enzymes under certain conditions are capable of reversing their actions, that is, of converting a soluble substance like sugar into an insoluble one such as starch, or of changing proteins to soluble forms so that they can be transported through the vascular system of the plant and stored in insoluble form in seeds, nuts, and roots.

The changes from sugar to starch may take place in leaves wherever certain plastids known as *amyloplasts* exist. These bodies have the power to form starch in the presence of a series of enzymes which first bring about the transformation of simple sugars to more complex sugars, and then to an intermediate substance between sugars and starches, called *dextrin*. Dextrin is changed into soluble starch by the enzyme, *amylase*, and finally the soluble starch is converted into insoluble starch by the enzyme, *coagulase*. Thus we see that the work of enzymes is absolutely essential to the life of the plant. Although plants and animals obtain their foods in different ways, they probably assimilate it in much the same manner, for foods serve exactly the same purposes in plants and in animals, namely, they are oxidized to release energy and they build up living matter.

How Food Is Used in the Plant Body

Although, basically, the uses of food are production of energy and making of protoplasm, certain substances are produced by plants which are not found in animals. For example, the plant cell is characterized by its cellulose wall which in old cells is strengthened by the addition of a complex substance, known as *lignin*. This forms the useful substance we call wood. In addition, other products characteristic of plant activity should be mentioned: the fatty substances, known as *cutin* and *suberin*, as well as waxes which give the "bloom" to certain fruits; the essential oils in resins, such as lemon, pepper-

mint, wintergreen, menthol, eucalyptus, camphor, and the like; various alkaloids; poisonous substances such as nicotine and strychnine; acids such as malic, citric, and tartaric. Plant protoplasm, in addition, as we have seen, manufactures many characteristic enzymes and produces pigments like the chlorophylls and carotins already mentioned. The carotin present in green grass fed to dairy cows gives the deeper color so much desired in cream and butter. Another interesting substance found in carotin is a precursor of Vitamin A which exists in plant bodies as a form of carotin and is probably transformed by the liver of animals into Vitamin A. This is another example showing how closely the lives of plants and animals are interwoven. (See pages 277-279.)



A diagram of the outer portion of a cross section of a wheat grain showing the various layers of tissues: *h*, the different integuments of the ovary and seed which make up the husk; *a*, the cells of "aleurone layer" of the endosperm, which are loaded with protein grains; and *b*, the layer of starch-bearing cells. (After Cobb.)

Respiration

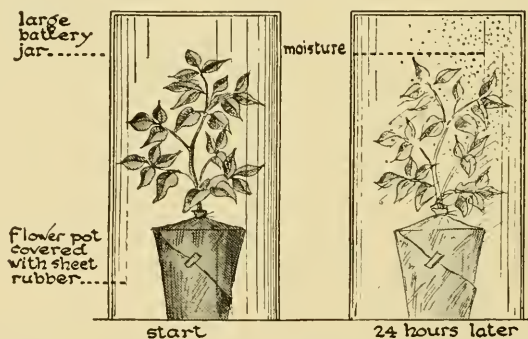
Respiration is essentially the same process in plants as in animals. In its simplest terms it is the release of potential energy from foods by means of the process of oxidation, whereby oxygen is used and carbon dioxide is given off. Glucose is perhaps the chief fuel of the plant body, although fats also serve this purpose. The latter are probably changed to sugar before actually being utilized in the respiratory process.

In order to have respiration take place, there must be an exchange of gases through a selectively permeable membrane. This means that there will be an exchange of oxygen and carbon dioxide in the cells where the oxidative process is taking place. Since respiration occurs in all living cells and since there is a greater volume of carbon dioxide and oxygen in parts of plants that are growing rapidly, it is obvious that growing roots must have a supply of oxygen. This is a reason for the loosening of soil particles around plants in cultivation to allow air to have access to the root hairs. The actual oxidative process is con-

siderably influenced by external conditions. Low temperatures slow up the process as do very high temperatures, there being an optimum temperature for each organism at which the rate of respiration goes on best. Seeds have survived a temperature of -250°C . Experiments with leaves show that the respiratory rate increases rapidly from 0° – 40°C ., from which point it falls slowly until the death of the organism. The amount of food present in the plant is a second factor influencing the rate of respiration, while the rate also varies with the amount of protoplasm in the cells. Light usually increases the respiratory rate, probably because of a parallel increase in food and temperature. It is also found that wave lengths which increase photosynthesis also increase the respiratory rate. Finally, the rate of respiration is greatly affected by poisons or anesthetics, at first being increased, but later slowing down rapidly. In brief, respiration in plants, as in animals, is induced by the action of enzymes, and results in the release of energy.

Transpiration

If a healthy potted plant is placed in a dry bell jar and left in the sun for a few minutes, drops of water are seen to gather on the inside of the jar. By covering the pot with a rubber tissue to exclude the

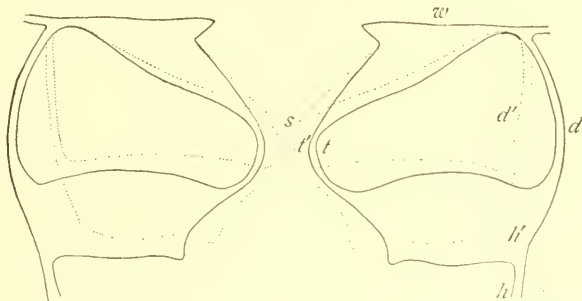


Experiment to show transpiration. Read your text and explain what has happened.

possibility of the evaporation of water through its surface and returning it to the jar under similar conditions, drops of moisture are again found after a time on the inner surface of the jar. Obviously, water must come out through the leaves or stem of the plant, a fact which can be demonstrated by weighing it before placing it in the jar, and

again after a brief period of exposure to sunlight, when it will be found to have lost weight. This loss of water takes place through the stomata and to some extent through the lenticels of the stem, a phenomenon closely associated with the process of photosynthesis, for which a relatively enormous amount of water is required. The reasons for this are that living matter is largely composed of water; that the process of food making cannot take place in plants unless the interior of their leaves are moist; and, in the third place, because water is one of the raw materials used in making sugar. The amount of water given off by plants through *transpiration* is very great. Early in the eighteenth century Stephen Hales (see p. 241) estimated that an average crop of cabbages loses from three to four tons of water per day per acre in warm weather. An acre of pasture grass is said to give off over 100 tons of water on a hot, dry day. A medium-sized tree will evaporate about five to six tons of water on a hot day. One writer, von Höhnel, estimated that an acre of large beech trees would transpire 30,000 barrels of water in one summer. Such figures show that a green plant loses water very rapidly during hot, dry days.

The amount of water lost differs greatly under different conditions. If the air is humid, or if the temperature is lowered, or if the temperature of the plant becomes low, the rate of transpiration is greatly

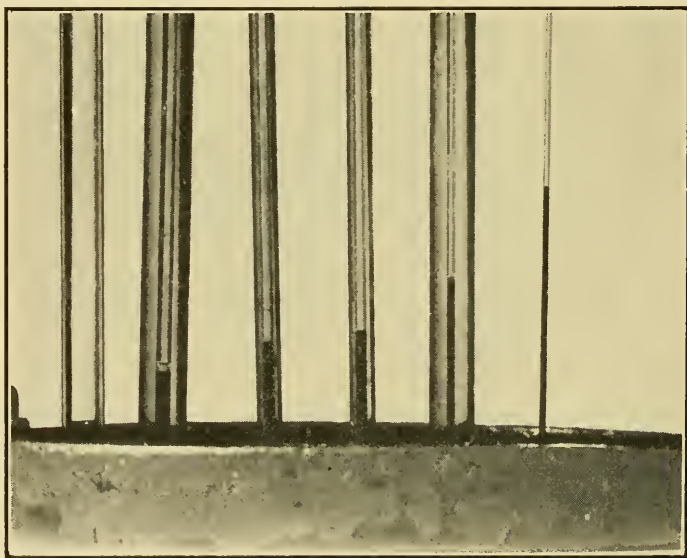


Diagrammatic cross section through a stoma to show movement of guard cells. The dotted lines show the closed position. Closure is brought about by the guard cells becoming more elongated and flattened, while the outer wall (*w*) remains in place, the ventral wall (*t*) and dorsal wall (*d*) assume the positions (*t'*) and (*d'*) moving toward the central slit (*s*) of the opening of the stoma. This movement is largely brought about through the change in position of the base or hinge (*h*) (*h'*) of the guard cell. (After Schwendener.)

reduced. The stomata tend to close under certain conditions, thus helping to prevent evaporation. The opening and closing of the stomata depend on changes in turgor of the guard cells. The stomata

open when the guard cells become more than normally turgid, but if the turgor of all of the living cells of the leaf is reduced by water loss, then the stomata seem to close automatically.

Light increases the amount of sugar formed in the guard cells because of the chloroplasts present, which results in a concentration of sugar, thereby causing a change in turgor. When the leaf is not illuminated by direct sunlight, or at night, the amount of sugar concentration in the guard cells becomes less, and consequently the stomata close. They usually are closed at night but remain open from shortly after sunrise until late in the afternoon. Toward the middle of the afternoon they begin to close, thus decreasing the amount of water lost in the latter part of the day. Plants wilt on hot, dry days because they cannot obtain water rapidly enough from the soil to make up for the loss through the leaves. Many adaptations are found in the leaves which help prevent this water loss, such as waterproofing of the outer cells, hairs on the leaf surface, the absence of leaves, as in the cactus where the minute leaves are early replaced by spines, or the actual turning of the leaves in order to place a small surface to the sun, as in the compass plant, thus causing the rate of evaporation to decrease.



Wright Pierce

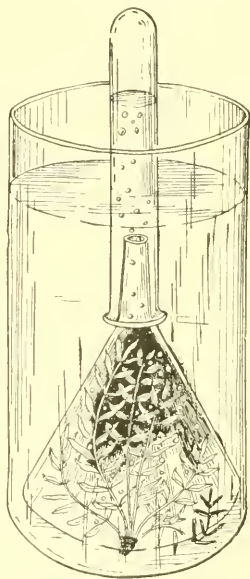
Capillary tubes of various sizes. Is there any relation between the size of the bore of the tube and the water level in the tube? Explain.

The Rise of Water in Plants

We have spoken of the passage of water from the root up the stem into the leaf. Osmotic pressure has been shown to be sufficient to start this column of water on its way up the stem, but it is not enough to account for the rise of water sometimes hundreds of feet into the air in the stems of trees. Several theories have been advanced to account for this phenomenon. The most satisfactory of these is the theory that such a column of water is held together by the force of cohesion. Experimental evidence shows that the cohesive quality of water in capillary tubes is very great. The core of water acts as a fine, extremely ductile wire. When we realize that a core of water in a tube $\frac{1}{200}$ of an inch in diameter will withstand a pressure of over 4600 pounds to the square inch, it will be seen that such resistance is a factor in the rise of water through the very tiny tubes found in the vascular bundles of a tree. Another factor in the rise of water in a plant or tree is the evaporation that takes place through the leaves, causing a pull on the cores of water in the tubes of the vascular bundles. During the daytime this is undoubtedly the chief factor in causing the rise of fluids in the stem.

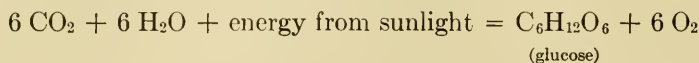
Production of Oxygen by Plants

A good many years ago the botanist Sachs proved that a green plant placed in the sunlight will give off oxygen, an experiment easily shown in the laboratory. If an aquatic plant such as *Elodea* is placed under an inverted funnel in a bell jar of water, and an inverted test tube of water is placed over the mouth of the funnel, bubbles of a gas are seen to leave the plant and gradually displace the water in the test tube. If a sufficient amount of this gas is collected, it can be tested with a glowing splint of wood and proved to be oxygen. The amount of the gas can be shown to depend approximately on the amount of sunlight and consequently the rate of photosynthesis. Going back to the formula which shows the making



How would you prove that the gas on the test tube was oxygen?

of sugar in the leaf, we find oxygen is given off as a by-product. The reaction may be expressed by the following formula :

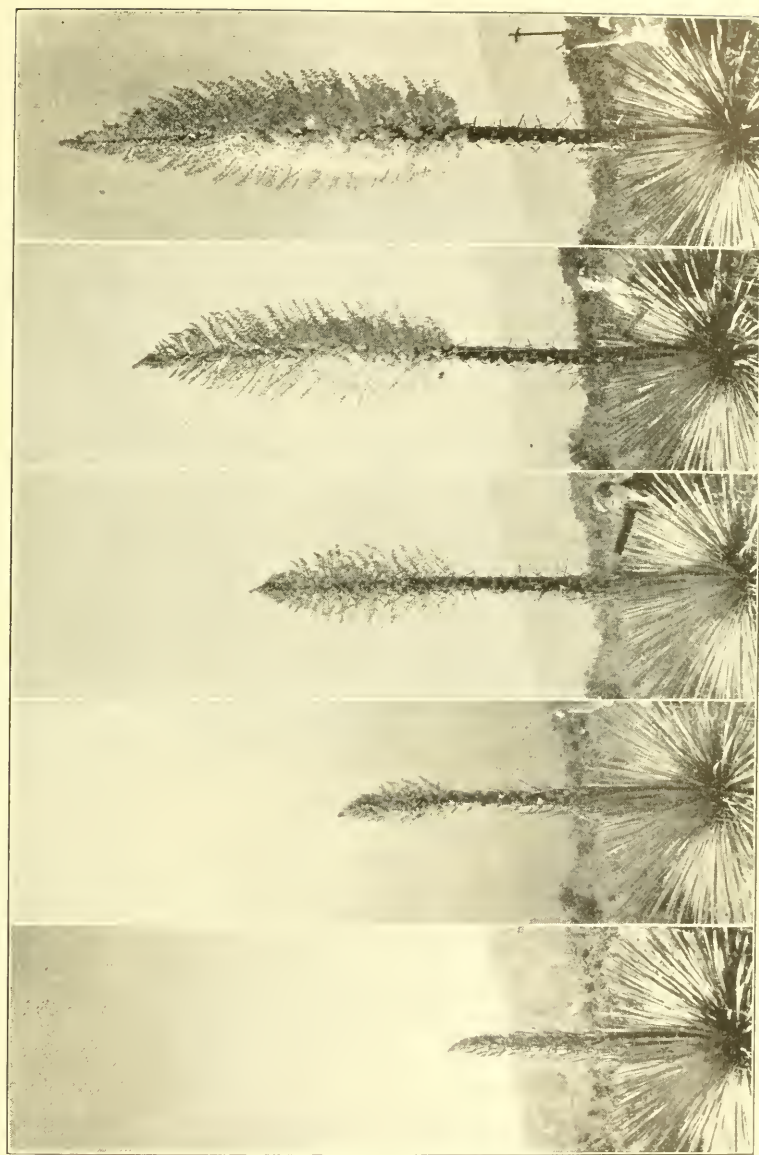


The value of this reaction to mankind is obvious. The by-product oxygen, which is poured into the air by green plants, is used by animals as well as plants in their respiratory processes. This exchange of oxygen and carbon dioxide by plants and animals gives us one of the most significant and far-reaching interrelationships seen in the organic world.

Briefly summing up the process of food making in plants we find that raw materials pass in the form of water and soil solutes from the soil through the root hairs and up the vascular bundles of xylem into the leaf, where water is taken into the individual green cells. Carbon dioxide reaches the cells from the air through the stomata and to a lesser extent probably in the water stream through the roots. In sunlight, the process of photosynthesis takes place. Elaborated foods made in the form of sugars may be changed by enzymes to starches and immediately stored in the leaf, or may be passed down through the sieve tubes of the phloem to various parts of the plant where they may be used or stored. Fats are probably synthesized from carbohydrates in the green parts of plants, while proteins seem to be formed in the cells irrespective of the presence of chlorophyll. Enzymes play a very important rôle both in the manufacture and in the use of food and are essential to respiration and oxidation. The digestive processes which go on in the leaf and other cells of the plant are also due to enzymes.

All that has been said in the preceding pages leads to the most important plant function, the reproduction of the species. With vegetative propagation by means of budding, runners, underground stems, tubers, or some of the other asexual means of continuing life, plants would not go far. To establish outposts in far-flung dominions they must have means of travel. These can only be obtained through free moving parts. Such plants are seeds and fruits, which may be dispersed by outside agencies far from the parent plant.

The life of the flowering plant culminates in the production of seeds and fruits. As growth progresses and food is accumulated, a time comes, sooner or later, when the energies of the plant are directed to the rapid production of the reproductive organs. Often this growth

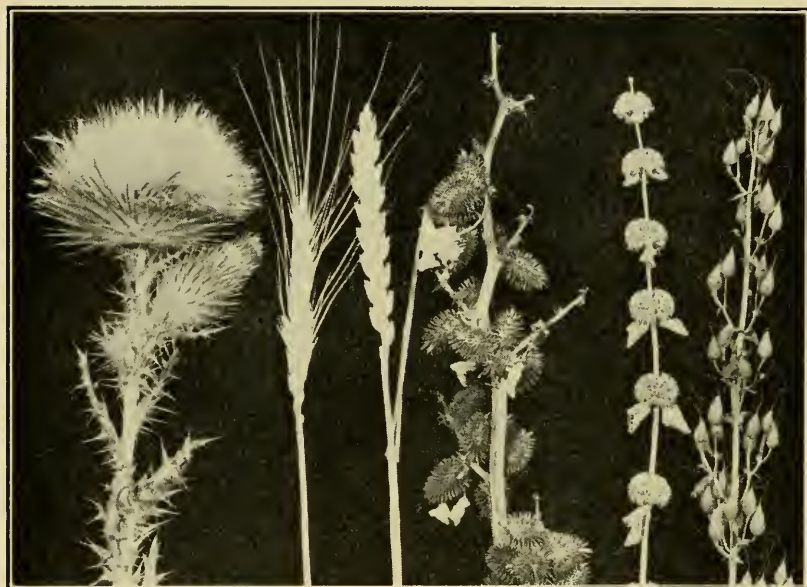


Wright Pierce

Development of the inflorescence of Spanish bayonet (*Yucca whipplei*). The photographs were taken at 72-hour intervals. Such rapid growth must be induced by plant hormones. Note the regularity of the growth curve.

is much more rapid than vegetative growth, and almost overnight, flowers appear.

The flower, as has been previously shown, holds the gametophyte generation of the plant and produces from fertilized eggs the seeds which hold the embryos or future plants. The fruit arises from the ovary of the flower, together with the parts that may be attached to it.



Wright Pierce

Adaptations in certain fruits for seed distribution. Can you describe the specific adaptation in each case?

Sometimes the parts are fleshy, forming edible fruits such as apples, pears, or plums; occasionally they form hard coverings such as the shells of nuts, and often they are prolonged into feathery outgrowths which aid in the distribution of the fruit and seeds. Enough has been said of distribution for us to grasp the significance of such adaptations, the ultimate purpose of which is to place the embryo in new areas so that when the seed germinates it may develop into a new plant and thus complete the life cycle.

SUGGESTED READINGS

Büsgen, M., and Münch, G. (translated by Thompson), *The Structure and Life of Forest Trees*, John Wiley & Sons, Inc., 1929.
Interesting and authentic.

Ganong, W. F., *The Living Plant*, Henry Holt & Co., 1913.

A not too technical account of how plants live.

Holman, R. M., and Robbins, W. W., *Textbook of General Botany*, 3rd ed., John Wiley & Sons, Inc., 1933.

Excellent chapter on photosynthesis.

Macdougall, D. T., *The Green Leaf*, D. Appleton & Co., 1930.

A fascinating account of the work of the green leaf. Readable and authentic.

Raber, O. L., *Principles of Plant Physiology*, The Macmillan Co., 1928.

A readable, but thoroughly scientific, book of reference. Especially valuable are chapters IV, VI, XVI, XIX, XX, XXI, XXII, and XXIV.

Sinnott, E. W., *Botany, Principles and Problems*, 3rd ed., McGraw-Hill Book Co., 1935.

Chapters IV, V, VI, VII, and VIII are useful for reference. Note the many suggestive questions at ends of chapters.

Wilson, C. L., and Haber, J. M., *Introduction to Plant Life*, Henry Holt & Co., 1935.

A general botany with a new point of view. Readable and usable.

THE METABOLIC MACHINERY OF ANIMALS

PREVIEW. *Section A.* Intake devices and how they function · Foods and their uses; energy producers; non-energy producers; vitamins · The activators — enzymes · Digestion in lower animals · Digestion in higher animals; methods of increasing digestive surfaces; parts of the digestive system: The oral cavity, the pharynx and esophagus, the stomach, the small intestine, the large intestine; the digestive glands and their enzymes: The salivary glands, the gastric glands, the intestinal glands, the pancreas, the liver, the secretions of the small intestine; absorption and the fate of absorbed foods · *Section B.* The how and why of circulation · Why a transportation system · Unspecialized transportation systems · Open circulatory systems · Closed circulatory systems: Among invertebrates; among vertebrates · The blood · The lymph · The conduits — arteries, veins, and capillaries · The heart · The aortic arches · The course of blood in the body; functions of the blood · *Section C.* Respiratory devices · Respiration; the protein, hemoglobin; external respiration: Respiratory papillae, respiratory pouches or trees, lung-books, the body surface, gills, tracheae, lungs, internal respiration; respiratory system in man · *Section D.* Excretory mechanisms · Excretion; types of excretory devices: Contractile vacuoles, intracellular excretion, other excretory devices; excretory devices of vertebrates — kidneys; the mammalian excretory system: The liver, other devices for waste elimination, the kidneys · Suggested readings.

PREVIEW

The body has often been compared to a machine. This analogy probably holds best when speaking of the preparation of food for combustion, the actual release of energy, and the resulting work done, as well as the disposal of the end products. It is this group of processes with which we will here be concerned. All animals are in constant competition with one another for food. If herbivorous they may be competing amongst themselves directly for plant food; if carnivorous, the competition is more indirect. Food, whether it is animal or plant by nature, is being continuously sought to maintain that complex series of processes called by some authors the "flame of life." An earlier unit describes how plants take raw materials, such as water, carbon dioxide, and nitrogenous compounds, and build them up into foods which may then be used or stored. The plant

in order to transport or to utilize this stored material must first break it down into simpler soluble compounds so that it may pass to the cells of the organism where it is utilized. A somewhat similar situation occurs in animals since complex protoplasmic material of animal or vegetable nature is taken in by the organism, broken down into simpler units, and then utilized or stored in the cells of the body during the normal processes of metabolism. This breakdown of foods is known as *digestion*, the intricacies of which make a fascinating study.

There are a number of important and interesting problems which present themselves at this point. The most important problems involved are: What is food and how is it digested? How is it disposed of after absorption? How is energy released? How are waste products removed? Briefly, they center around questions which we should answer, for it is both interesting and profitable to understand something of the human machine. Consequently, although other animals are mentioned, the fact should not be lost sight of that we have a selfish interest and are anxious to know about ourselves. The answers to these stimulating questions will be found in the discussions that follow.

SECTION A. INTAKE DEVICES AND HOW THEY FUNCTION

Foods and Their Uses

Any substance taken into the body that can be utilized for the release of energy, for the regulation of body processes, or for the building and repair of tissues falls into the category of food. If this broad definition of food is adopted, then water, inorganic salts, vitamins, carbohydrates, proteins, and fats should be included. Food substances may be further subdivided into those capable of releasing the latent or potential energy bound up within the molecule and those which, though non-energy producers, are still essential to life. Energy which is so essential to the metabolism of an organism is largely secured through the breakdown of a complex series of molecules into simpler ones. Non-energy producers are equally as essential to the well-being of the organism since water and inorganic salts, for example, are necessary for the maintenance of the normal composition of tissue.

Energy Producers

Carbohydrates, proteins, and fats are the sources from which energy within the animal body is derived. Of these, carbohydrates and fats

are more readily oxidizable than proteins, a fact which is taken advantage of by the Eskimo, who secures much of his energy from oils and fats. The white man in the tropics uses carbohydrates chiefly for the same reason.

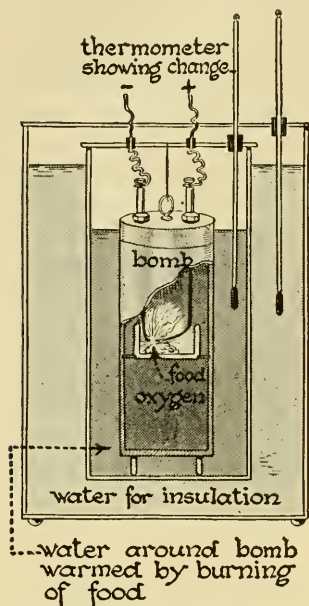


Diagram of a bomb calorimeter. How does it work?

No two foods contain the same percentages of carbohydrates, proteins, or fats. Atwater analyzed many foods in the calorimeter which bears his name. Such a bomb calorimeter consists essentially of an outer insulated chamber surrounding one containing a known amount of water. The inner compartment in turn encloses the metallic chamber in which a certain amount of oxygen and food are placed and burned by means of an electric current. The amount of heat generated is transmitted to the water in the chamber surrounding the bomb and the value of this in terms of *calories* is then determined. It will be recalled

that a calorie is the amount of heat necessary to raise one gram of water one degree centigrade.

Non-Energy Producers

Three widely diversified groups are represented by water, inorganic salts, and vitamins. All serve the common end of keeping the animal in a state of well-being, yet each group does so in a very different way.

Water constitutes a large portion of the animal body which may compose even as much as five sixths of the daily intake. Estimates vary from 62 to nearly 75 per cent of water by weight in the case of the human body. The quantity in the different tissues varies according to the metabolic state of the tissues of the organism. It is well established that bone contains only about 22 per cent of water, while other organs, as the liver, muscles, kidney, and brain, contain much

larger amounts. In the case of man the amount of water in the adult body remains approximately the same under normal conditions, but if decreased beyond a certain point intolerable thirst results. On the other hand, if the amount of water is increased, the blood pressure is raised in the renal capillaries and the excretion of urine is stimulated. The consumption of a liberal supply of water is a characteristic biological process as it favors the removal or dilution of waste and poisonous materials from the body.

Along with water, the presence of certain chemical elements such as sodium, potassium, calcium, magnesium, iodine, iron, chlorine, phosphorus, sulphur, silicon, and fluorine is necessary to maintain the various kinds of tissues. Much experimental work has been performed upon various animals, indicating the importance of a proper balance of these elements in the diet. The absolute withdrawal of any of these may end in the death of the organism.

Since these salts form a part of all tissues and serve a variety of functions it is impossible to mention all of them. The important part which calcium salts, for example, play in the formation of bone is well realized. In this connection it has been said that there is enough lime in a human body "to whitewash a small hen-coop."

Certain parts of foods rich in carbohydrates contain indigestible material that serve as roughage and are useful in stimulating the muscles of the large intestine. Bran, whole wheat, fresh vegetables, and fruit provide some of the best sources of these materials. Other examples may be found in the cellulose of plant cells which can be used as food by only a few animals.

Flavorings, stimulants, and condiments, such as pepper, mustard, tea, coffee, and cocoa, are not true foods. However, they have a real value in making food more appetizing.

Vitamins

It might seem that an organism could be kept alive, well, and healthy upon a balanced diet of the necessary inorganic salts and water, together with energy producers and tissue builders, such as amino acids, carbohydrates, and proteins. Modern scientific work has dispelled this illusion by a series of laboratory experiments and by observations of experiments performed in nature. We now know that regulating substances, called vitamins, are some of the most essential ingredients of all foods.

These health regulators have been lettered and are known as Vitamins A, B, C, D, E, and G. More recent experiments show that what was previously believed to be a single vitamin may prove to be a mixture of two discrete fractions. These may be referred to as A¹, A², and so on, or they may be given a new letter, as, for example, H. Thus Vitamin B has become subdivided into B or B¹, the *anti-neuritic* vitamin, the absence of which results in a disease known as *beriberi*, and B² or G, the *antipellagric* vitamin, the lack of which produces pellagra.

The initiation of scientific work in this field is usually credited to Eijkman, who in 1897 produced beriberi in fowls by feeding them on certain restricted diets. This was really "putting the cart before the horse," for through the pioneering contributions of Grijns (1901) it was shown that the disease is produced by the *absence* of some essential constituent of the diet. This important conclusion has been corroborated and extended materially through the efforts of Hopkins in England and McCollum, Eddy, Osborne, and Mendel in the United States. Research in this field has taken great strides since 1910 and is still going on.

Vitamin A is found in the fatty and oily constituents of such foods as butter and cream, egg yolk, liver, carrots, cod-liver oil, yellow corn, and leafy vegetables. Experiments have demonstrated that this vitamin is a necessary adjunct to growth. Without it rats die, but if even such minute amounts as 0.005 mg. of the purified vitamin are added to the normal diet, the sick animals are restored to general health.

Scurvy has long been the curse of those embarking upon long sea voyages or expeditions where it has been necessary to provide diets deficient in fresh meats and vegetables. It has also been known that such a disease can be cured by the use of fresh vegetables and fruits. As early as 1804, lemon juice was issued regularly to British sailors, who became known thereafter as "limeys." It is only within comparatively recent years, however, that this remedy has been known to be due to the presence of Vitamin C, the *antiscorbutic vitamin*. It may be secured most conveniently in oranges, lemons, or tomatoes. Apparently food can be dried or canned without marked injury to the vitamin. Almost as soon as this vitamin is eliminated from the diet degenerative changes begin, although some time is necessary before the first symptoms appear. This has been designated as the *depletion period*.

Vitamin D, better known as the *antirachitic vitamin*, is chiefly concerned with maintaining an adequate supply of phosphorus and calcium in the blood, bones, and teeth. The discovery of this vitamin is associated with a study of rickets. Early workers noted that cod-liver oil had a beneficial effect. The cure was attributed to Vitamin A until, in 1923, McCollum of the Johns Hopkins University and his co-workers showed that the efficacy of cod-liver oil remained even after treatment which destroyed Vitamin A, an observation which led to the identification of Vitamin D. The best sources of this vitamin are cod-liver oil, butter, and egg yolk.

More recently it has been shown that the precursor or "pro-vitamin" of Vitamin D, a substance known as *ergosterol*, will yield the vitamin after irradiation with ultraviolet light. Ultraviolet rays of the sun, or X-rays, are likewise a great help in overcoming rickets. At the present time four methods are used to increase the amount of Vitamin D in the body: (1) irradiation of the skin by exposure to sunlight or other sources of ultraviolet light; (2) the addition of cod-liver oil to the diet; (3) the introduction of irradiated ergosterol (*viosterol*); and (4) the use of Vitamin D concentrates in foods. This latter method has been most successfully introduced by Zucker, by the addition of this concentrate to milk, thus facilitating its administration to young children.

A survey of the prevalence of rickets shows that this disease is much more common than has been supposed, especially in young children, a fact strikingly brought out when 83 per cent of a group of over 200 children from New Haven, Connecticut, who were examined by X-ray, showed mild evidence of rickets.

Vitamin E is commonly known as the *antisterility vitamin*. This important substance has been shown to be present in greatest quantity in lettuce, whole wheat, and, to a somewhat lesser degree, in egg yolk and milk. It is fat-soluble and quite resistant to heat. There is evidence suggesting that the animal body has the ability to store this vitamin.

The Activators — Enzymes

It will be recalled that the metabolic processes of plants and animals include about every type of reaction known to the chemist. It has been demonstrated that enzymes not only are essential for digestion, but also that all chemical changes in the body are mediated by enzymes. Glucose may be taken as an example. The decomposition

and oxidation of this simple sugar produces over 100 different substances. The living cell yields only a few of these, and then in a regular succession. Such remarkable specificity and speed of reaction in the living cell is largely due to the action of enzymes which have the property of accelerating some particular reaction. As was pointed out previously (p. 128), enzymes may be regarded as *catalysts* because they are not expended and primarily serve to speed up a reaction.

While the properties of particular enzymes will be discussed in some detail as they are encountered later, certain of their general characteristics as determined by the biochemist will be briefly mentioned. In this connection it is interesting to note that six enzymes have been prepared in crystalline form, and *all* are proteins. While this evidence is not conclusive it suggests the probable chemical nature of a considerable number of these activators. Most enzymes have what the chemist calls a reversible reaction and so may be capable of serving as a catalyst for both hydrolyses and syntheses. However, it should not be forgotten that under some conditions an action may be practically irreversible. Such is the case with glucose which, although theoretically capable of reacting in several different ways, continues to react in one direction because of the presence and concentration of a particular enzyme. Nearly all enzymes appear to have an optimum working temperature of about 40° C. (104° F.). Furthermore, enzymes appear to be specialized, at least to the extent of requiring a definite acidity or alkalinity of the surrounding medium. One classic example is the pepsin of the stomach, which reacts only in an acid environment.

Many enzymes seem to have the common function of splitting complex molecules into simpler ones, a process usually accomplished through the addition of water, or hydrolysis. Enzymes acting in this manner may be described as *hydrolytic*, the term being formed by adding the suffix *lytic* to the Greek stem for *water*. The enzymes themselves are designated by adding the ending *ase* to the name of the substance upon which each acts, as, for example, *maltase* or *lipase*, signifying, respectively, action upon maltose or the lipins (fats). Such activators may be spoken of collectively as *hydrolases* since they act through the addition of water. Similarly the catalyzing enzymes for oxidations and reductions are spoken of collectively as *oxidases*. A few other enzymes do not fall into either of the above categories.

Digestion in Lower Animals

Digestion within the animal kingdom is primarily of two sorts, *intracellular* taking place within the cell and *extracellular* which is carried on outside the boundaries of the cell. Sometimes both types of digestion occur in the same organism. The complexity of the picture among one-celled forms may be appreciated when it is realized that within the confines of a single cell are carried on all the essential processes characteristic of a many-celled organism.

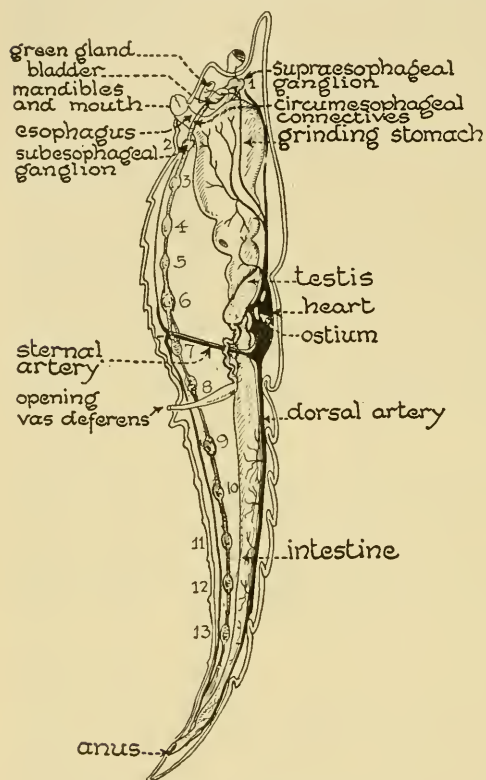
Euglena, for example, shows evidence of being a rather generalized physiological type (see page 157). Within the group to which it belongs three types of nutrition are found: (1) *holophytic nutrition* carried on by the aid of chlorophyll; (2) *saprophytic nutrition* corresponding to that carried on by the chlorophyll-less molds and fungi; and (3) *holozoic nutrition*, involving the ingestion of solid food particles, a type characteristic of animals. Both *Ameba* and *Paramecium* are characterized by relatively simple intracellular digestion, the potential food reaching the interior of the cell by means of a food vacuole, the indigestible particles being egested from the cell later.

In sponges ingestion and digestion principally occur in the *collared*, or *choanoflagellate*, cells where food vacuoles are formed and wastes egested. The nutritive material is then passed from one cell to the other and, according to Hegner, may be circulated to a certain extent by wandering ameboid cells found in the middle region by a similar intracellular action.

In the coelenterates one first finds evidence of *extracellular digestion*. Here a special layer of cells called the *endoderm*, which lines the primitive *gastrovascular cavity*, is set aside. This cavity appears in *Hydra* as a simple sac lined by cells possessing the ability to send out either flagella or pseudopodia. Some of these cells are glandular and secrete digestive enzymes which are passed into the gastrovascular cavity, making digestion an *extracellular* process. A certain amount of intracellular digestion does take place, however, since some of the food particles are surrounded by pseudopodia and so brought within the walls of the endodermal cells.

Most of the parts of the digestive system found in vertebrates are represented in the earthworm (see page 189). The digestive system of a crayfish will be discussed here as representative of the Arthropoda. Its food consists of such organisms as frogs, tadpoles, small

fish, insect larvae, snails, and decaying organic matter. The maxillipeds and maxillae around the mouth are used to hold the food while the mandibles crush it into small pieces that are then passed into the esophagus. The large stomach contains a series of chitinous ossicles, forming the *gastric mill*, which grinds the food. When the



Sagittal section of crayfish showing digestive system.

food has been broken up sufficiently, it passes through the strainer into the pyloric chamber, where the *digestive glands* or "liver" empty their secretions through hepatic ducts. These glands secrete enzymes which digest both proteins and fats. From this chamber the dissolved food passes into the intestine where nutritive material is absorbed through the intestinal wall.

Digestion in Higher Animals

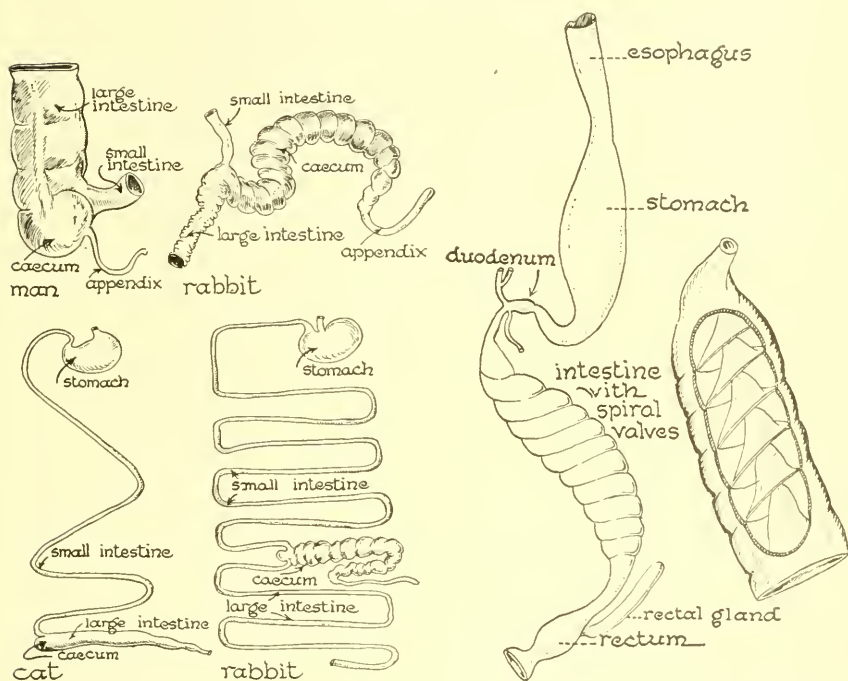
In the vertebrate series the parts of the digestive systems are analogous and even homologous with some invertebrate structures. All except the lowest and parasitic types of invertebrates are characterized by an *alimentary canal*. Dif-

ferences which occur in the digestive tracts of vertebrates are largely attributable to the different kinds of food handled by different types of systems. Carnivores digest their foods more rapidly than herbivores and so can get along with a shorter alimentary tract.

Methods of Increasing Digestive Surfaces

One of the first problems in digestion is the production of an adequate absorptive surface. Greater digestive surfaces may be pro-

cured by increasing the length or diameter of the alimentary tract, or by the formation of pockets, or *caeca*, of different sizes and shapes. A carnivore such as a cat has an alimentary tract which is only three to five times the body length, whereas a cow, being herbivorous, supports one over twenty times the length of its body. Man, who is intermediate as well as an "omnivorous beast," has one about ten times longer

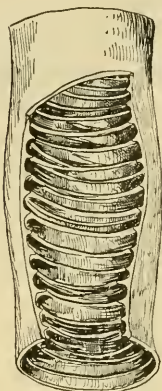


Comparison of digestive tracts of a carnivore and herbivore. How can the differences in the size of the caeca and length of the gut be explained? (After Wells, Huxley, and Wells).

Alimentary canal of the dogfish. State the function of the valvular intestine. What are the principal differences between this digestive tract and that of the rabbit?

than the body. A modification quite characteristic of some groups is the caecum, which is noticeably large in rodents. Other types of caeca, like the *pyloric caeca*, sometimes occur near the juncture of the stomach and the intestine among fishes, and there should be mentioned here the longitudinal fold, or typhlosole, of the earthworm. When such a longitudinal fold is twisted spirally, there results a structure known as a *spiral valve*, which is characteristic of sharks.

Other devices such as throwing the surface into transverse ridges are quite common, for example, in man they occur in the intestine and colon as *plicae circulares*.



Circular folds or *plicae circulares* in the intestine of man. These occur from the duodenum to the anus.

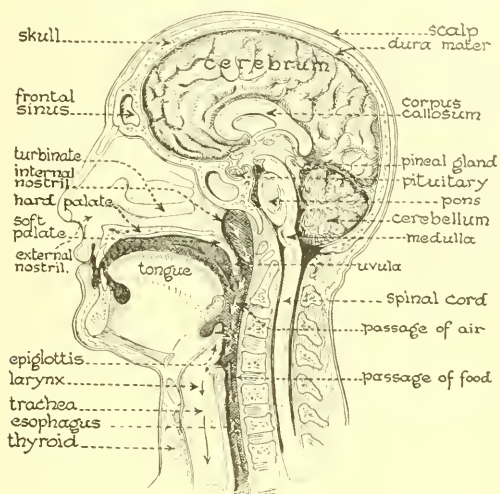
Parts of the Digestive System

THE ORAL CAVITY. The various mouth cavities of vertebrates are all developed for one fundamental purpose, namely, the ingestion of food. The mouth cavity is specialized in many different ways and is further complicated in air-breathing forms by the necessity for completely separating the air-intake apparatus from the digestive tract. This is accomplished quite readily in water-inhabiting species through the use of gill-slits. In land forms, however, the *external nares* (nostrils) and associated nasal passages are dorsal and the lungs ventral to the opening of the digestive tract. It is necessary therefore to arrange in the pharyngeal region for the crossing of the air passageways over the food tube. This separation is facilitated in most forms by the presence of a hard bony plate known as the *hard palate* that lines the roof of the mouth. At the posterior end of the hard palate is attached a flap of soft tissue, the *soft palate*, which further expedites the separation of respiratory and digestive tracts.

The oral cavity is lined throughout by a *mucous membrane* the cells of which secrete mucus that serves as a lubricant facilitating the passage of food. This same tissue is found throughout the entire surface of the food tube. In various parts of the alimentary canal are found openings of various glands which add their digestive ferments to the mucus. These glands will be considered in detail under the digestive processes of man.

Usually the surface of the palate, especially the posterior part, known as the *soft palate* and *uvula*, contains numerous mucus-secreting glands called the palatine glands. The secretions of these glands help to keep the cavity of the mouth moist. In many animals, especially carnivores, there appear a number of washboardlike *palatine ridges* that appear to be an adaptation to enable its owner to secure a surer grip upon the unfortunate victim that has been seized in its jaws. The large, bulky tongue, which occupies practically the entire floor of the buccal cavity, likewise plays an important rôle in eating.

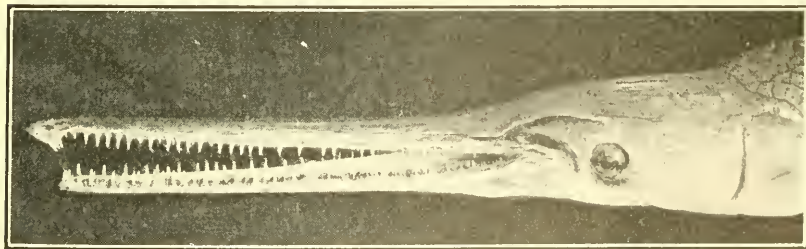
Teeth are found in the vertebrate group from fishes up to man. While derived from a common embryological source, they have developed in many different ways during the course of evolution to serve such various uses as grasping, grinding, or cutting food. In



Sagittal section of human head.

many of the lower fishes they are unspecialized and are continuously being replaced as worn out. Thus the shark always has a new set developing behind the old, a device suggestive of an endless chain.

The garpike has a series of long, pointed, unspecialized teeth which are used merely as holdfast organs. In such types, teeth are not crushing or tearing devices. The amphibia and reptiles show little tendency toward specialization, except among the poisonous reptiles



N. Y. State Conservation Dept.

Unspecialized teeth of the garpike, *Lepisosteus osseus*.

with their fangs and the toothless jawed turtles that make up for the lack of teeth by sharp cutting horny beaks suggestive of the bird's beak.

The greatest development and specialization of teeth occurs among the mammals. According to their shape and function they are divided



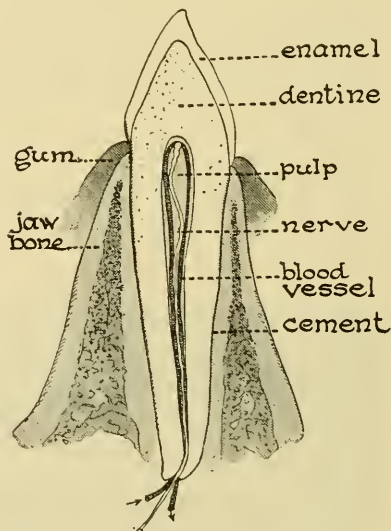
Skull of a squirrel, a rodent (left), and a cat, carnivore (right). Compare carefully for differences in dentition.

into *incisors*, or cutting chisels, *canines*, or graspers and tearers, *premolars*, or grinders, and *molars*, or crushers. Here we find a real relationship between the type of teeth and the diet of the organism. In the carnivores, for example, the anterior grinders are so constructed that

they slide like shears while the canines are specialized for grasping animal food, the back molars tending towards degeneracy. In herbivorous animals except the rodents the front teeth, especially the canines, are reduced while the molars become greatly developed.

The teeth of man play a definite rôle in the mechanical preparation of food for digestion. Instead of holding the prey, they crush, grind, and tear the food so that a greater surface may be exposed to the action of digestive juices. Man like some other organisms develops more than one set of teeth. The first, or milk teeth, are only twenty in number while there are thirty-two secondary, or permanent teeth.

Each tooth is divisible into an upper gum-protruding *crown*, a lower embedded *root*, and an intermediate *neck*. The outer part of the crown is protected by the hardest substance of the body, *enamel*, that surrounds the bony *dentine*. This in turn protects



Sagittal section through a tooth. Why are cavities painful?

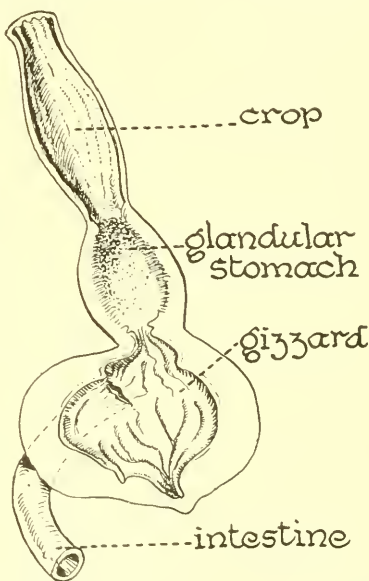
the *pulp cavity* where during the life of the tooth nerves and blood vessels are housed. Each tooth is held in a socket of the jaw by means of another hard tissue, the *cement*.

Nearly every vertebrate organism possesses some sort of tongue which serves a variety of functions. The lassoing tongue so characteristic of certain amphibia, for example, is provided with special glands secreting glutinous mucus that helps to ensnare insects. In lizards the tongue may become extremely long and extensile, it also serving to aid in capturing food, while among some of the birds it may even be adapted for impaling insects, as in the case of the "horny, spearlike tongue" of the woodpecker. The mammalian tongue is likewise specialized, for in many of the herbivores it is definitely muscular and prehensile, being used to grasp tufts of grass which are then cut off against the lower incisors, while in dogs and cats it is used as a spoon to take up liquids. The tongue helps mechanically in swallowing and in man it also plays a vital part in speech. The tongue of higher forms is covered with a variety of sensory structures which test the various foods before they are swallowed.

THE PHARYNX AND ESOPHAGUS.

This region is both membranous and muscular. We may think of the pharynx in all air or land vertebrates as being an irregular cavity supplied with openings. Dorsally and anteriorly are two *posterior nares*, or internal nostrils, laterally the openings of the *Eustachian tubes* connecting with the middle ear, while medianly and ventrally lies the opening to the oral cavity.

Posteriorly there are two openings, one down the esophagus and the other, the *glottis*, leading into the trachea (see fig., page 285). Above the soft palate is a mass of lymphoid tissue, known as the *adenoids*, or *pharyngeal tonsils*, while anteriorly and laterally lie the true, or *palatine tonsils*.

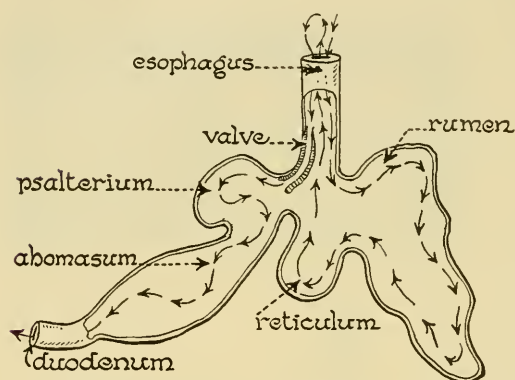


"Stomach" of bird. What are the functions of the different parts?

THE STOMACH. The stomach of vertebrates is likewise subject to considerable variation. In the case of grain-eating birds a distended esophageal region, the *crop*, is developed for the storage of food. Below this region is the stomach proper, divisible into a *glandular stomach*, which secretes digestive enzymes, and a muscular *gizzard*,

or grinding stomach, that compensates for the absence of teeth.

A second example of an outstandingly different type of stomach appears in the compound stomach of ruminants as, for example, a cow. Here there are four parts, namely, the *rumen*, *reticulum*, *psalterium*, and *abomasum*, the first two being derivatives of the esophagus.

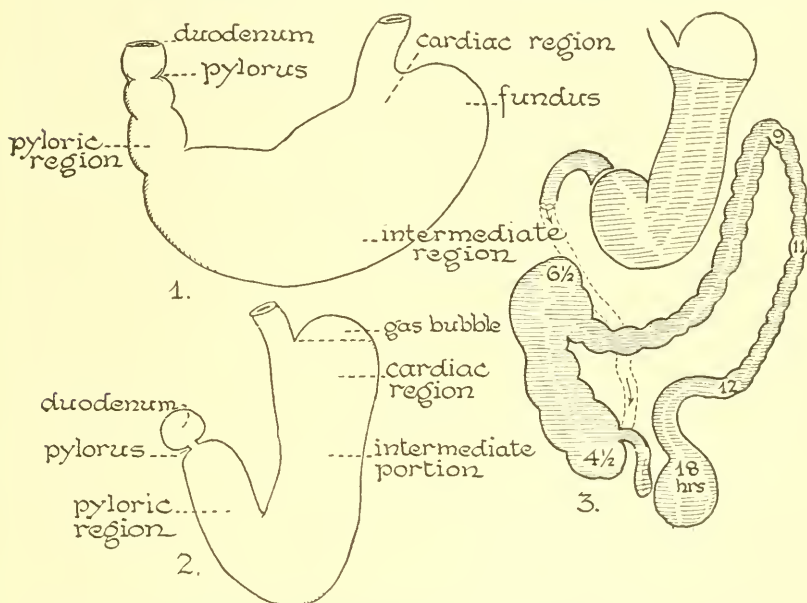


Stomach of a ruminant. What is the function of the valve and what is the significance of "chewing the cud"? (After Walter.)

The more solid food is temporarily stored in the rumen, or paunch, as fast as it is ingested, gradually being passed on into the *reticulum* where it is mixed further with digestive juices and softened. From time to time, ball-like masses of this food are regurgitated from the reticulum and thoroughly mixed with saliva by chewing. This process is commonly known as "chewing the cud." After a time the food is swallowed a second time and if the chewing has sufficiently reduced the mass to a small slippery wad, it passes directly into the *psalterium* and thence to the *abomasum*, where it undergoes gastric digestion.

The human stomach as compared with the compound stomach of the ruminants is of a more simple type, although divisible both histologically and physiologically into several parts. The esophagus enters an expanded *cardiac* region the entrance of which is guarded by a ringlike sphincter muscle. The stomach is always curved to some extent, the inner or concave surface being known as the *lesser curvature* and the outer or convex as the *greater curvature*. The blind, rounded part of the stomach lying to the left and usually opposite the entrance of the esophagus is called the *fundus*, while the region closest to the point of entrance of the esophagus is called the *cardiac portion*;

the lower end is known as the *pyloric* part, the extreme limit of which is indicated by a groove called the *pylorus*. The pyloric and fundic parts of the stomach differ in the nature of their musculature as well as in their physiological activity during digestion. The pyloric part is separated from the small intestine by a sphincter muscle, called the *sphincter pylorus*. The shape and position of the stomach may vary according to the posture and amount of food ingested. Thus, while the stomach is supposed to lie in an "obliquely transverse position,"

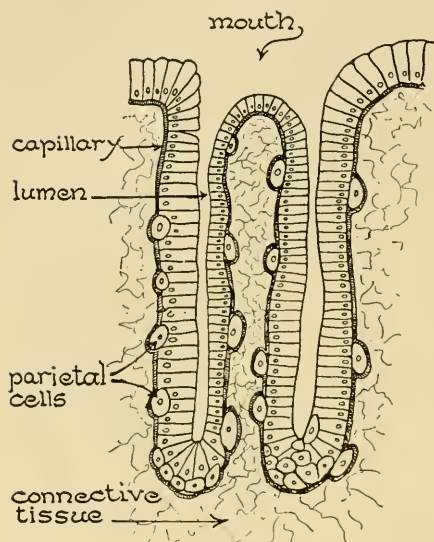


The human stomach (1) as usually depicted, (2) the shape and position of the stomach as shown by X-ray, (3) stomach and large intestine showing position of food at varying hours after ingestion. (After Howell.)

it really assumes a J-shape as detected by X-rays. The folded wall of the fundus is dotted with thousands of tiny pits, the mouths of gastric glands, or little tubes the epithelial lining of which secretes the gastric juice. (See page 294.)

As in the case of the remainder of the digestive tract, the stomach wall is made up of several layers of tissue. Beginning with the inside is the soft, thick, glandular *mucosa*, usually thrown into folds, or *rugae*, which tend to disappear when the stomach is distended. A second layer, the *submucosa*, composed of loose connective tissue

lies between the mucous and muscular layers. The latter is made up of three layers of involuntary muscles, an inner, poorly developed oblique layer over which lies a circular layer that in turn is enclosed by an outer layer of longitudinal muscles. The fourth or outermost



A typical gastric gland. Explain the functioning of each part.

coat is known as the *serosa*, which is continuous with the peritoneum and as such covers both organs and their associated glands. This covering is moist and serves not only as a protection but also facilitates the movement of one portion over the other.

Food in order to reach the stomach must be rolled into *boluses* and then swallowed. This is a complicated reflex movement which apparently may be more or less voluntarily initiated as the bolus passes into the pharyngeal region, past the trap door (*epiglottis*) which covers the opening into the larynx and trachea.

Failure of this flap to close properly results in food "going down the wrong way," when the mass is expelled after a paroxysm of choking and coughing.

Liquids and soft foods reach the stomach in about 0.1 second while more solid boluses are passed along by a series of slow-moving wavelike contractions, called *peristalsis*. Boluses require about six seconds to reach the stomach. The entrance of food into the stomach is probably controlled by the cardiac sphincter. Solid food may remain in the stomach for several hours. One of the first noteworthy observations of this process was made upon Alexis St. Martin, a Canadian voyageur who was studied by Beaumont in 1847. The adventurer had a permanent opening into his stomach as a result of a gunshot wound, which permitted direct observation of processes going on within the stomach. These and other studies indicate that the fundus largely functions as a reservoir which retains the bulk of the food while the more muscular pyloric portion churns it, forcing it periodically into

the first part of the small intestine (*duodenum*). It is interesting to remember that carbohydrates pass out of the stomach soon after ingestion, remaining only about one half as long as proteins. Fats likewise remain a long time within the stomach even when combined with other foodstuffs.

THE SMALL INTESTINE. The intestine is subdivided into a region principally devoted to absorption of digested foods, namely the *small intestine* and the *large intestine* which to a lesser extent is devoted to a continuation of absorption, and to the collection of waste products.

The entire small intestine of man, some twenty feet in length and about an inch in diameter, is concerned with the digestion and absorption of foods and their transfer to the blood stream. It is also believed that some waste

materials are actually excreted into the lumen of the gut. These functions are accomplished by a series of adaptations, one of which is the extraordinary length of the small intestine, together with numerous small circular ridges, *plicae circulares*, which serve the double function of giving an increased absorptive surface and of retarding the rate of passage of foodstuffs. The other but by no means the least important adaptation, is the presence of millions of small knoblike projections, or *villi*. These tiny structures according to Howell move actively either by lateral lashings or by extension and retraction. It is believed that these movements are associated with the act of absorption and probably play an important part in emptying the lymph sac, or *lacteal*, lying in the center of each villus. By means of the *plicae circulares* and the *villi*, the small intestine is estimated to have an absorbing surface equal to twice that of the surface of man's body.

The internal structure of the villus is best seen in a longitudinal section. The outer wall is composed of a thin layer of *epithelial cells* in which the more complex fats are resynthesized before being



I

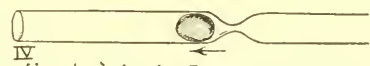


II



III

dividing motion shown in I, II, III. Rhythmic, segmenting movements.



IV

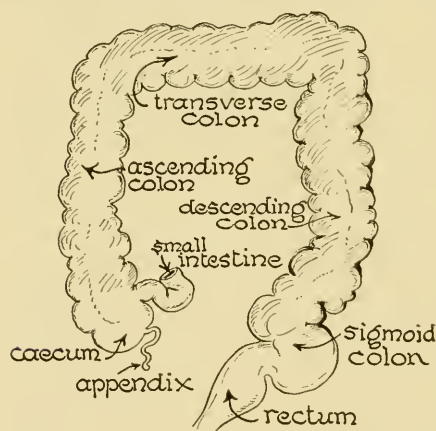
diastalsis is Cannon's name for the peristaltic wave which moves along the intestine, preceded by inhibition

Diagram to illustrate peristalsis.

passed to the *lacteals*. Beneath this is a mass of connective tissue permeated by a network of capillaries that in turn surround the central lymph channel (*lacteal*) into which fat is absorbed. Between the villi are found the openings of the *intestinal glands* which are associated with the compound *duodenal glands* in the production of intestinal juice. Aggregations of two types of lymph nodules appear, *solitary lymph nodes* about the size of a pin head and groups spoken of as *Peyer's patches*. The latter are sometimes the seat of local inflammation and ulceration as in typhoid fever.

The same four coats which were found about the stomach occur in the small intestine except that the oblique layer of muscles is missing, while the mucous layer is very thick and vascular.

THE LARGE INTESTINE. The large intestine of man has somewhat the same anatomical structure as the small intestine except that it lacks villi and has a greater diameter. It is separable into a shallow blind pouch at the juncture of the small and large intestines, and an enlarged *colon* and *rectum*, terminating with the anus. The entrance of material into the large intestine is regulated by the *ileo-caecal valve*, formed by two flaps of mucous membrane, which permits entry into it but effectively prevents back flow. At the end of the caecum



is a vestigial continuation of it, the *vermiform appendix*, a blind pouch usually about three inches long. Inflammation of this structure usually results in a condition recognized as *appendicitis*.

The caecum, appendix, and colons of man. Why is the appendix so frequently the seat of bacterial infections?

The *colon* of man is divisible into four parts known respectively as the *ascending*, *transverse*, *descending*, and *sigmoid* colons. In other mammals, the colon may not always be separated into these parts although the juncture of the small and large intestines is clearly set off by an *ileo-caecal*

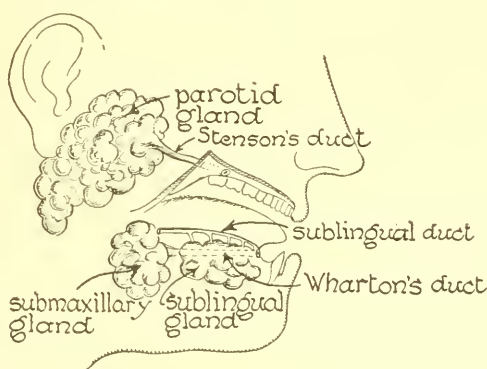
valve and a caecum. The anus is guarded by both an external and an internal sphincter which keep the orifice closed except during defecation. The external sphincter is composed of striated muscle

and is under the direct control of the will, while the internal sphincter is derived from one of the coats of the rectum and consists of unstriated or involuntary muscle.

The process of absorption is thought to be continued to a limited extent in the large intestine as its contents are retained for a considerable time. The secretions of this region are alkaline, containing much mucus but apparently no enzymes. By the time the contents reach the large intestine the water content is considerably reduced through absorption. Bacteria, which compose nearly 50 per cent of the human feces, carry on putrefactive protein fermentation in the large intestine.

The Digestive Glands and Their Enzymes

The chemical processes of digestion occur largely through the activity of enzymes which are produced in a variety of different glands. Practically all vertebrates possess *salivary* and *gastric glands*, a *liver*, *pancreas*, and various *intestinal glands*.



Salivary glands in man. What enzyme do these glands secrete? (After Walter.)

THE SALIVARY GLANDS. Saliva, which acts as a lubricant in the mouth, is manufactured in the cells of three pairs of glands that empty into the mouth by ducts, and which are called, according to their position, the *parotid* (beside the ear), the *submaxillary* (under the jawbone), and the *sublingual* (under the tongue). In addition, the salivary glands, which are absent in most aquatic forms, secrete a digestive enzyme, *ptyalin*, that acts upon starch in an alkaline medium, splitting it partially or entirely into a disaccharide sugar known as *maltose*. Ptyalin is present in all mammals except those which are entirely carnivorous.

The chewing process theoretically mixes food with saliva thoroughly but in man the bolus is invariably swallowed before the ptyalin has completed its action. Recent studies indicate that salivary digestion continues in the stomach for some time until stopped by the hydrochloric acid of the stomach.

THE GASTRIC GLANDS. The inner surface of the stomach is covered with cells producing mucus, the entire region being dotted with thousands of tiny *gastric glands* secreting gastric juice. Most of the lumen of each gland is lined by columnar epithelial cells called *chief cells*, while between the basement membrane and the chief cells of the glands lie scattered *parietal cells*. The chief cells of the neck of the gland secrete mucus while those lower down secrete an inactivated enzyme or zymogen, called *pepsinogen*. Oval *parietal cells* secrete hydrochloric acid, which activates the pepsinogen, converting it into an active enzyme (*pepsin*), that, in the presence of this acid, breaks down proteins to the intermediate products, *peptones* and *proteoses*. Gastric juice is slightly acid in its chemical reaction, containing about 0.2–0.4 per cent of free hydrochloric acid together with another enzyme called *rennin*. The latter curdles or coagulates *casein*, a protein found in milk, which is the basis of cheese. After milk is curdled pepsin is able to act upon it. “Junket” tablets, which contain rennin, are used for this purpose in the preparation of a dessert which has milk as a basis.

The stomach is the place where the digestion of proteins is initiated and where digestion of carbohydrates may be continued. Some investigators believe that emulsified fats such as cream are digested by a *gastric lipase*. However, since saponification and emulsification must take place before absorption, and *after* the fats reach the intestine, it appears probable that fats undergo no digestive changes in the stomach.

Although little or no absorption takes place in the stomach, under certain conditions water, salts, alcohol, and drugs may be absorbed. There appears little evidence at present to support the contention that sugars and peptones are appreciably absorbed in this organ.

Food, after being mixed with gastric juice, becomes increasingly liquid and is known as *chyme*, in which state it passes through the pylorus. The next step is facilitated by the muscular movements of the small intestine, which are primarily of two kinds. The first, *peristalsis*, helps pass the food slowly along the intestine. The second, *rhythmical contractions* or *segmentation*, may be described as a series of

local constrictions occurring at points where the food masses lie. Such contractions break up the food into a number of segments enabling the enzymes to reach all parts.

THE INTESTINAL GLANDS. The partly digested food in the small intestine comes in contact almost simultaneously with secretions from the liver, pancreas, and intestinal glands.

THE PANCREAS. As the acid chyme enters the duodenum it activates some "prohormone," probably *prosecretin*, which is first absorbed into the capillaries of the blood vessels and then carried throughout the body. Some secretin ultimately reaches the pancreas, which is then stimulated to further activity causing the chemical secretion of the *pancreatic juice*. The pancreas is one of the most important digestive glands in the human body. It is anatomically a rather diffuse structure resembling the salivary glands in form. Its duct, joined with the bile duct from the liver, empties into the small intestine a short distance below the pylorus near the juncture of the duodenum and the ileum.

The secretions of the pancreas or "stomach sweet bread" contain three groups of enzymes, (1) *amyllopsin*, (2) *trypsin* and some *crepsin*, and (3) *lipase*, which act respectively upon carbohydrates, proteins, and fats. The first, *amyllopsin*, breaks down starches by hydrolysis to double sugars, finally yielding the disaccharide *maltose*, and *dextrin*. Maltose is further broken down by *maltase* into a monosaccharide, *glucose* (*dextrose*), which may then be absorbed.

Second, in order for absorption to take place in proteins they must be broken down into their constituent *amino acids* by the action of at least *trypsin* and *crepsin*. Protein material reaches the first portion of the small intestine, or *duodenum*, in the acid chyme which is generally neutralized somewhat before the proteolytic enzymes do their work.

Third, fats, thus far unchanged in the process of digestion except to be melted by the heat of the body, are then emulsified by the bile and finally are hydrolyzed in the intestine by the action of *lipase* into *glycerol* (glycerin), and also one or more *fatty acids*. These are absorbed by the epithelial cells of the villi, resynthesized into more complex fats, and passed into the lymph channels, or lacteals.

Aside from the noteworthy office of "secretor of the pancreatic juice," the pancreas has another important function. One might say that it is one of the "board of directors" governing the health of the body. When the sugar content of the blood becomes too high

and sugar appears in the urine, *diabetes*, a disease caused by a dearth of *insulin* in the blood, occurs. Insulin is a hormone formed by groups of cells collectively called the *islands of Langerhans*, which function as ductless glands. Since 1921, when Banting, Best, and Macleod found that insulin injected into animals showing symptoms of diabetes caused a decrease of sugar in blood and urine, this pancreatic hormone has become a veritable lifesaver to man.

THE LIVER. The liver is the largest gland in the body, and in man is found just below the diaphragm, a little to the right of the mid line of the body. It is not primarily a digestive gland, although it secretes daily about a quart of bile, which while containing no enzymes may have the power of rendering the lipase of the pancreatic fluid more active. Bile when mixed with the pancreatic juice helps *emulsify* liquid fats into minute separate droplets, in this way preparing them for digestion. Certain substances in the bile aid especially in the absorption of fats. Another important function of bile is the neutralization (wholly or in part) of the acid chyme when it enters the duodenum, thus preparing it for the action of the pancreatic juice. Bile also stimulates the peristaltic movements of the intestine, thus preventing extreme constipation. It is also thought by some to have a slight antiseptic effect in the intestine. Bile seems to be mostly a waste product from the blood. Its color is due to certain substances which result from the destruction of worn-out red corpuscles of the blood.

Besides these digestive and excretory functions the liver is also concerned with the formation of a nitrogenous waste, *urea*, $\text{CO}(\text{NH}_2)_2$. This product is largely produced in the liver, whence it is transferred to the blood and carried to the kidneys where it is excreted.

Perhaps the most important function of the liver is the formation and storing of an animal starch, or *glycogen*. The liver is supplied with blood from two sources, some from the heart, but a greater amount directly from the walls of the stomach and intestine. This latter blood supply is very rich in food materials and from it the cells of the liver take out sugars in the form of glucose (dextrose), which is synthesized into animal starch in the liver. Glycogen is stored in the liver until such time as energy is needed. It is then reconverted to the monosaccharide form, glucose, and carried by the blood stream to the tissues where it is oxidized with an accompanying release of energy. A limited amount of glycogen may be found and stored in the muscles and it is also thought to be produced from proteins and

possibly fats as well as carbohydrates. Storage of glycogen in the liver has been demonstrated by taking two rabbits, which were fed heavily on clover after a period of starvation. After allowing suitable time for digestion and assimilation, one rabbit was killed and glycogen was demonstrated in the liver cells, while the other was given strenuous exercise before being sacrificed to science. Upon examination the second rabbit showed a greatly reduced quantity of glycogen in the liver cells.

THE SECRETIONS OF THE SMALL INTESTINE. There can be no doubt of the importance of the part played by the pancreas and liver in digestion which is supplemented by secretions of the intestinal wall, called collectively *intestinal juice*, or *succus entericus*, a substance containing five important enzymes secreted by small intestinal glands of the mucosa (see figure of villus). The first, *enterokinase*, acts as a co-ferment on proteins and was formerly thought to be an activator for trypsinogen. *Erepsin*, while appearing to be the same as that appearing in the pancreas, hydrolyzes peptides to amino acids; *maltase*, as previously noted, converts maltose into dextrose, while *lactase* hydrolyzes milk sugar into the simple compounds of galactose and dextrose, and *invertase* converts ordinary table sugar into levulose and dextrose. The last three are frequently spoken of collectively as *inverting enzymes*.

It should be remembered that the large intestine produces no enzymes, wherefore it is assumed that little or no digestion takes place there. The bacteria of the large intestine attack any protein material which has escaped digestion and break it down by putrefactive fermentation.

Absorption and the Fate of Absorbed Foods

In animals that possess circulatory systems the diffusible end-products of foods are passed through the epithelium of the gut into the blood stream, or, in the case of fats, through the lymphatics to the blood. In higher vertebrates most of the absorption takes place in the walls of the small intestine. While diffusion and osmosis are important factors in the passage of food and water through the walls of the intestine, many physiologists agree that the living matter in the cells lining the intestine exerts energy which affects the absorption of the substances that pass into the blood and lacteals. This is proved by the fact that if these cells are injured or poisoned, absorption follows the laws of osmosis and diffusion. Ordinarily the cells lining

the intestine are like tiny chemical laboratories. Carbohydrates in the form of monosaccharides, or glucose (dextrose), are absorbed through the epithelial cells lining the villi and reach the capillaries of the circulatory system. Proteins in the form of amino acids likewise reach the blood stream in this way. Glycerin and fatty acids are absorbed by the epithelial cells, resynthesized in these minute chemical laboratories into more complex fats, and are then passed on to the lymph channels, *lacteals*, of the lymphatic system in the villi. This

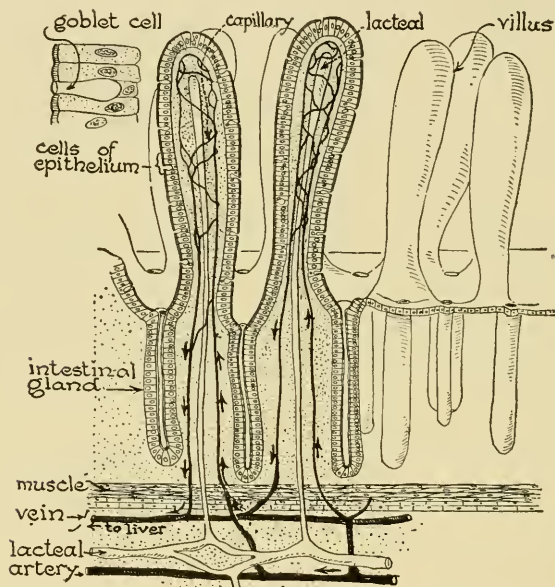
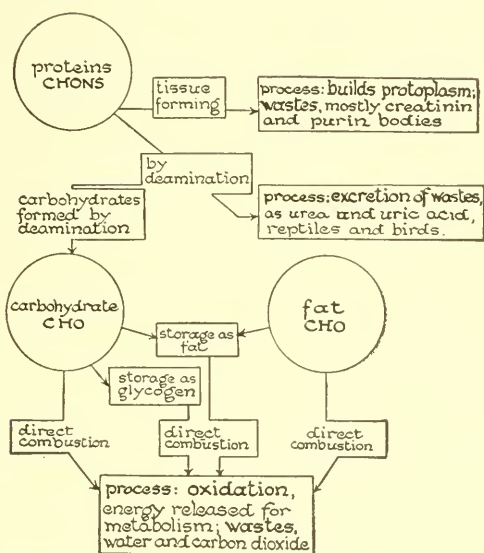


Diagram of intestinal villi and glands. Can you explain the part played by the villi in absorbing digested "foods"?

fluid or *lymph* then passes into the other lymphatics, eventually reaching the blood through the *thoracic duct* which enters the jugular vein in the neck. On the other hand, simple sugars and amino acids pass directly into the blood and reach the blood vessels which carry them to the liver, where, as we have seen, sugar is taken from the blood and stored as *glycogen*. From the liver the food within the blood is carried to the heart and is then pumped to the tissues of the body. A large amount of water and some salts are also absorbed through the walls of the stomach and intestines. The greatest loss of water, however, occurs in the large intestine.

We have already traced the changes taking place in the absorbed sugars, chiefly dextrose, and have shown how they may be taken from the blood stream, converted into glycogen, and temporarily stored. Some of this sugar is usually available in the circulating blood which contains 0.1 to 0.15 per cent of it. The muscles likewise store glycogen that is used as work is done. Carbon dioxide and water are the final products of carbohydrate oxidation. Experimental evidence indicates that glycogen may be produced from some of the metabolic



Summary of metabolic processes.

products of proteins.¹ The production of glycogen from fats still lacks conclusive evidence, although there is some indication of indirect conversion.

The proteins which have been absorbed may be utilized in two ways: (1) in the rebuilding of broken-down protoplasm; (2) in the supply of energy for work. Consequently, protein substances are often differentiated into *tissue builders* and *energy producers*.

Fats ultimately reach the circulating blood from which they are taken up and used by the various tissues. Fats may be oxidized within the cell to supply energy. In such cases the final products are carbon dioxide and water. When excess fat is eaten it is held in

¹ Howell, *Textbook on Physiology*, 12th ed. Saunders, p. 869.

reserve in adipose tissues. Some animals must build up a large supply of fat so that they may draw upon it when their food supply is low. This is particularly true of such hibernating animals as the bear that emerges in the spring from a period of sleep at a time when its fat supply is depleted. Fat storage in man, upon the other hand, is entirely unnecessary from a physiological point of view and, due to the frequency of meals, is usually quite involuntary.

SECTION B. THE HOW AND WHY OF CIRCULATION

Why a Transportation System?

Within the body of nearly all of the metazoa evidence of a highly specialized system of internal transportation is found. The degree of development of such a system depends mostly upon the size of the organism, the amount of activity it displays, the complexity of its internal organization, and whether or not it is a warm blooded animal. The size of the body, the speed and frequency with which the animal moves are some of the factors that determine how "specialized and well trained" the "handy man" about the body, *i.e.*, the circulatory system, must be. With specialization comes greater division of labor, yet specialized parts such as nerve cells and muscle fibers require not only nourishment but also the elimination of waste products from their immediate vicinity as well as favorable conditions of temperature. The solution of the problem is met in part by more or less bathing all cells in lymph which serves for bringing food to the cells and for the removal of wastes. In order to secure a continuous food supply and to insure the adequate removal of wastes such a transportation system is necessary.

In all but the simplest organisms such a system is composed of vessels containing lymph which brings its contents to locations where it can eliminate the wastes, take up the energy-releasing oxygen, and pick up food for the tissues. Without such a system the organism cannot exist.

Unspecialized Transportation Systems

Unicellular animals obviously have no need for a circulatory system as each individual cell is in a position to excrete its own wastes and secure oxygen and food for itself through its own cell membrane. Even in slightly more specialized forms, such as the

coelenterates, there is no need for a specialized transportation system for circulating digested foodstuffs other than that furnished by the ramifications of the gastrovascular system. Since the organism is composed of only two layers of cells, each is capable of securing the necessary materials for its metabolism either from outside of the body or from a neighboring cell lining the cavity.

However, in the flatworm *Planaria*, a more highly developed gastrovascular system appears. In animals of this type the gut ramifies between nonspecialized cells composing the parenchymatous tissue in which the various organ systems of the body are embedded. As the food is digested it is circulated directly throughout the gastrovascular cavity by means of contractions of the body, the food readily passing from the branched gut to surrounding tissues of the body by diffusion. The waste products reach the gastrovascular cavity and by similar muscular contractions are passed to the outside, or they may be excreted through the flame cell excretory system (see page 320).

Still further advances in the development of specialized circulatory devices occur in types having a body cavity, or coelom. In a number of invertebrates the coelom is filled with a lymphlike fluid which may contain corpuscles resembling white corpuscles, or leucocytes. This may be looked upon as an advance over the gastrovascular type of distributing system. And, as we ascend the animal scale and the circulatory devices tend to become more complex, we note the tendency to develop definite tubes in which the circulatory fluids may be confined. These types are usually muscular and contractions of the body facilitate the movement of the fluid. In segmented forms like the earthworm the coelomic fluid supplements the work of the regular circulatory system.

Open Circulatory Systems

This type of transportation reaches its peak of development in the crustacea. The lobster or crayfish, both aquatic forms, furnish familiar examples, in which the blood serves the three purposes of respiration, transportation of foodstuffs, and the elimination of wastes. As in all well-developed circulatory systems, there is a muscular pumping mechanism, or *heart*, which, by its contractions forces the blood along a group of so-called arteries. These in turn usually break down into smaller vessels terminating in the tissues. The blood bathes the tissues and then finds its way back, usually along

a system of sinuses, through the gills to the *pericardial sinus* surrounding the heart. It passes into the heart by means of a series of openings called *ostia*, guarded by one-way valves.

Insects, a still more highly specialized group, have a very direct respiratory system called a *tracheal system*, which takes over the job usually handled by the blood stream, bringing the oxygen directly to the tissues through a network of tubules, or *tracheae*. This has been discussed previously in detail (pages 209-210).

Closed Circulatory Systems

Among Invertebrates

Systems of this general type are found in a large and diversified group of organisms beginning with the invertebrates and extending throughout the vertebrate group. The motive power of such circulatory devices consists essentially of a central pumping plant or heart, from which extends a series of arteries that break down into minute capillaries in the tissues and then pass into gradually larger vessels known as veins which return the blood to the heart. Somewhere in the capillary circuit the blood is aerated, giving off carbon dioxide and taking in oxygen. The earthworm furnishes an example of such a system in the invertebrates.

Among Vertebrates

In all of the vertebrates there is a well-developed closed type of circulatory system, although the supplementary lymphatic system might be construed as a sort of open system. In order to understand the work performed by these systems we must turn our attention to the various component parts involved and consider their functions.

The Blood

Blood is a red fluid which, examined microscopically, is seen to be composed of three types of corpuscles, red and white, circulating in a liquid *plasma*, and the much smaller *blood platelets*. The first contains hemoglobin, which combines with oxygen in a loose combination forming *oxyhemoglobin*, useful in respiration. The white corpuscles, on the other hand, are the scavengers of the body. They are amoeboid in shape and are concerned, in part at least, with the defense of the body against bacterial invasion. Under certain stimuli great

numbers of one sort or the other of these blood cells are produced. The blood platelets are now generally believed to play an important rôle in the clotting of blood.

In the web of a frog's foot the blood may be seen rushing along through relatively large vessels which break down into smaller ones until reaching the capillaries, through which the corpuscles slide in single file at a much slower gait. It is here that oxygen and food diffuse by osmosis to the surrounding lymph and so reach the tissues. Under the microscope the blood appears to be traveling at a headlong pace, due to the fact that this instrument magnifies only space without reference to time. The pace of the corpuscles quickens again as they reach the larger *venules* which, after anastomosing, ultimately lead to the heart as *veins*. Two interesting facts might be mentioned here, one dealing with the capillaries and the other with blood. Dr. Krogh, a Nobel prize winner from Denmark, says that if an average human being was selected and all of his capillaries were opened up and spread out flat, their total area would nearly cover that encompassed by an average city block. The other fact centers about the numbers of corpuscles present, of which various estimates have been made. In normal women and men there should be 4,500,000 to 5,000,000 red corpuscles (*erythrocytes*) per cubic millimeter of blood, while somewhere between 5000 and 10,000, normally about 7500 white corpuscles (*leucocytes*), is considered an average count. Red corpuscles vary in number with altitude, a greater number being necessary in high altitudes where less oxygen is present in the atmosphere and, consequently, greater numbers are needed to transport the amount of air necessary for life.

The plasma of the blood also contains a great variety of protective substances which are known under the general heading of *antibodies*. They are induced by bacteria and other parasites which, acting as foreign proteins, stimulate some living body cells to manufacture them (see page 626) and turn their protective substances loose into the blood stream.

The Lymph

Even though capillaries are distributed widely, each is surrounded by narrow *lymph spaces*, that are filled with plasma and white corpuscles, the latter being mostly *lymphocytes*. Lymph is concerned with the transportation of food, oxygen, and other substances necessary for the successful metabolism of the organism. It is lymph which

comes into contact with the tissues and serves as the go-between for the blood and cells. Lymph gradually flows from the lymph spaces into *lymph capillaries*, which in turn unite to form larger and larger *lymph vessels*, interspersed with numerous *lymph glands* and *lymph nodes*. Finally the lymph vessels unite into a large *thoracic duct* emptying into the *jugular vein* in the neck region.



Principal lymph channels of man. Note the abundance of lymph vessels in the region of the intestine. What function do they serve? Find the thoracic duct emptying into the jugular vein.

The Conduits — Arteries, Veins, and Capillaries

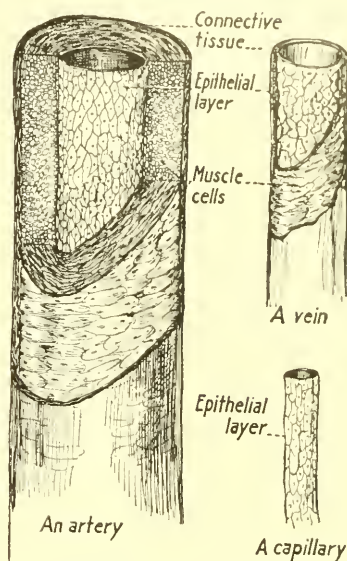
Having considered the “stuff” that blood is made of, we can now turn to a consideration of the vessels through which it passes. The chief function of the capillaries centers about the exchange of the products of metabolism with the lymph. Some of the plasma of the blood actually transudes through the walls of the capillaries, while certain types of leucocytes also pass through the walls, which are composed of nothing more or less than a single-celled layer of epithelial cells, called *endothelium*.

Distinct structural differences exist between the capillaries and the *arteries* and *veins* of all vertebrates. Both arteries and veins are covered externally by a rough protective coat of *connective tissue*. Between this and the inner endothelial lining lies a layer of *elastic muscular fibers*. In veins, this layer is relatively thin, while in the arteries, it is quite well developed, probably being correlated with the greater pressure to which arteries are subjected as evidenced by the periodic spurting of blood whenever an artery is cut.

In the veins blood is prevented from flowing back away from the heart by a series of cuplike valves that open in the direction of the blood-flow toward the heart but which close when the reversed movement is attempted. They are quite similar to the *semilunar valves* of the heart (page 308).

Veins collapse when cut while arteries do not. This fact proved a stumbling block to the proper interpretation of the anatomy and

physiology of arteries and veins by the early scientists. William Harvey (1578-1657) was the first to understand thoroughly the circulatory system, but other earlier and contemporary workers were not far behind him. The great artist, Leonardo da Vinci (1452-1519), left in manuscript numerous drawings and notes on the heart and other vessels, stating that the aorta "subdivides into as many principal branches as there are principal parts to be nourished, branches which continue to ramify *ad infinitum*." Vesalius (1514-1564) in his famous anatomical treatise, *Fabrica*, first published in 1543, expressed doubt as to the existence of the connecting "pores" between the two sides of the heart. This was an attack upon one of the main features of the teachings of Galen, who believed there was "an ebb and flow of blood within both veins and arteries throughout the system." The former contained crude blood and the arteries vitalized blood.



Comparison of the walls of an artery, vein, and capillary.

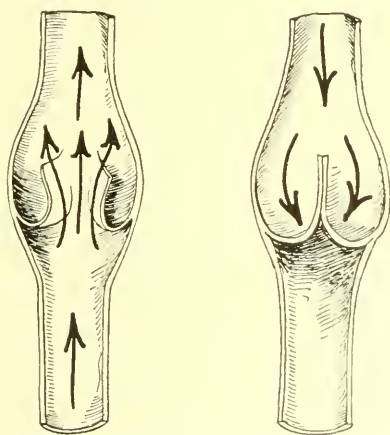


Diagram showing how valves of a vein prevent the back flow of blood.

The former contained crude blood and the arteries vitalized blood. Yet neither Vesalius nor Galen (130-200 A.D.) apparently understood the circulatory system.

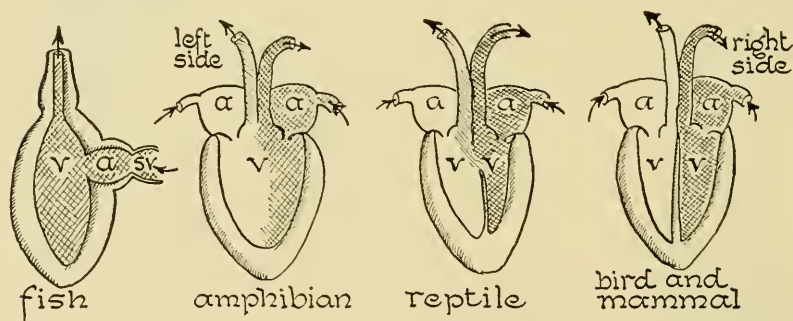
William Harvey is rightfully known as the father of physiology for in 1616 he began presenting his views on the circulation of the blood. His book, however, did not appear until 1628. In it we find evidence for the thesis that the heart is the pump,¹ that the arteries dilate passively as the heart forces the blood into them, that the blood goes from the right ventricle through the lungs to the left auricle,

¹ All stages of this phase of the argument are not outlined fully.

and that the amount and rate of flow of the blood from the heart makes it necessary to assume that most of it must return to the heart. This latter fact was shown by assuming that the ventricle held only two ounces; then, if the pulse beats 72 times per minute, in an hour it would force $72 \times 60 \times 2$, or 8640 ounces, or 540 pounds, into the aorta, which is considerably more than the weight of man. The return of the blood to the heart is accomplished by veins, thus completing the circuit. This summarizes briefly the gist of Harvey's contributions on circulation. Small wonder that after so many misleading beliefs this master should be acclaimed for his careful thinking and his accurate observations upon the action of the heart. His study involved examinations of about forty species of animals, and ultimately led to the fundamental concept of the circulation of blood.

The Heart

The vertebrate heart is really a pumping station which in its simplest form, as found in the fishes, consists of a receiving *auricle* and a pumping *ventricle*. Back flow is prevented by a series of valves placed at strategic points. Ascending the vertebrate scale and leaving behind water-inhabiting forms, we find the circulatory system

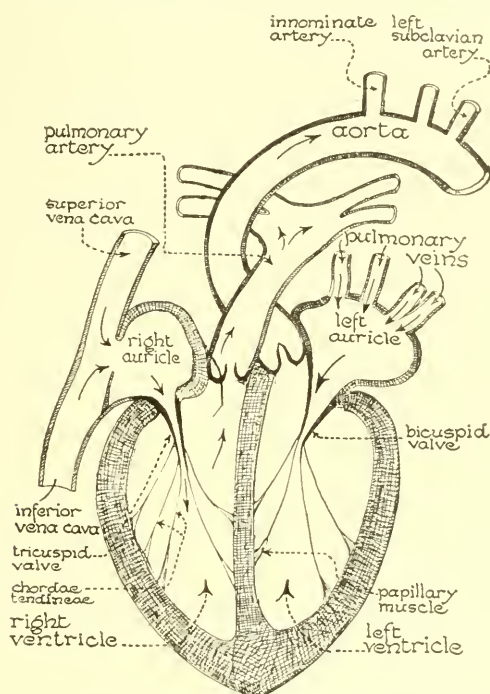


Evolution of four-chambered heart. Contrast situation in fish and amphibia with reptiles, birds, and mammals.

becoming more complicated and the heart evolving from a two-chambered form, typical of fish, to a four-chambered type found in birds and mammals. Intermediate stages in this progression appear in the amphibia and reptiles.

The heart of man is a cone-shaped, muscular organ about the size of the fist. It is surrounded by a loose membranous bag called the

pericardium, the inner lining of which covers the heart and secretes the pericardial fluid in which the organ lies. The heart of an adult mammal may be divided into a right and left side, each having no direct internal connection with the other. Each half may likewise



A section through the mammalian heart. Read the text carefully and trace the course of blood through the heart.

be divided transversely into an upper relatively thin-walled auricle and a more muscular lower ventricle. The right side contains unoxygenated or venous blood, while the left auricle and ventricle contain arterial blood saturated with oxygen.

The right auricle receives the venous blood by two vessels known as the *superior vena cava*, or *precava*, entering on the anterior surface and bringing the blood from the head and neck, and the *inferior vena cava*, or *postcava*, which empties into the lower portion of the right auricle, returning the blood from parts of the body below the diaphragm. The blood passes into the right ventricle through the *tricuspid valve* which, as the name suggests, is composed of three irregularly shaped flaps. The tips of these flaps project into the

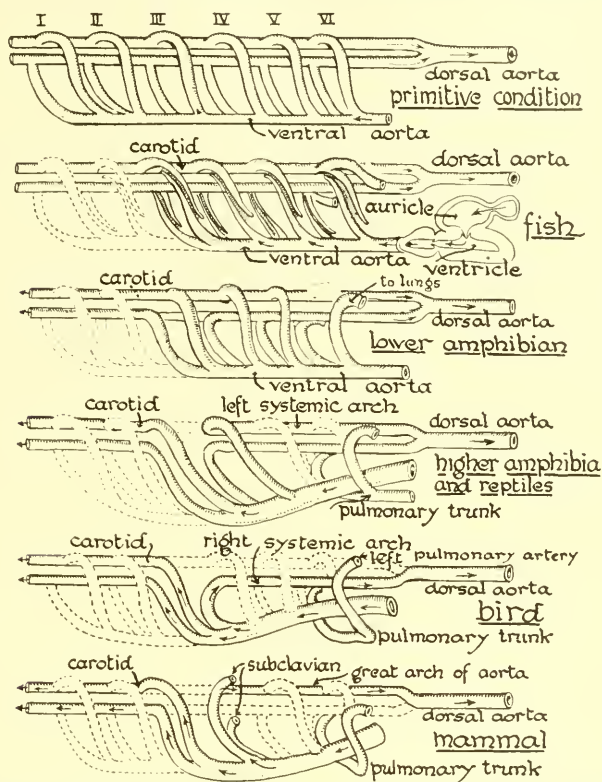
ventricle, where they are attached by tendinous chords, the *chordae tendineae*, to small muscular projections called the *papillary muscles*, extending from the wall of the ventricle. Back flow is prevented upon contraction of the ventricle by the closing of the flaps due to pressure, while a reversal of their position is prevented by the *chordae tendineae* and the contraction of the *papillary muscles*. Thus the blood passes from the right ventricle into the *pulmonary artery*, the lower portion of which is guarded against back flow by three half-moon-shaped cups, called the *semilunar valves*. The blood has now started toward the lungs through the *pulmonary artery*, which is the only artery carrying unoxygenated blood, to the lungs, where carbon dioxide is given off and oxygen taken in by the hemoglobin in the red blood corpuscles. It then passes into one of the larger *pulmonary veins* and so reaches the *left auricle* of the heart. Here the process described for the right half of the heart is repeated except that the left auricular-ventricular orifice is guarded by the *bicuspid valve*, while the semilunar valves on this side of the heart lie in the *aorta* which is the outgoing artery carrying the blood about the body.

The "beating" of the heart is a more complicated story than can be elaborated here. First, as the ventricles relax, blood flows from the veins into the auricles and ventricles, then the two auricles contract simultaneously, further dilating the two ventricles. This is followed by the immediate contraction of the two ventricles. Then follows a brief period of relaxation or rest during which the auricles and ventricles are being filled again, after which the cycle is repeated. This forces the blood from the heart in a series of spurts, accounting for the type of bleeding noted when an artery is severed, and for the expansion of the elastic arteries as the blood is forced out of the heart into them.

The Aortic Arches

As the blood goes out through the pulmonary artery it is passing through the embryological remains of the *aortic arches*. Originally six in number, these paired aortic arches are of great interest to students of evolution since embryological and comparative anatomical studies have yielded a very striking picture of the changes in this region involved in the shift of vertebrates from water to land. From fishes on up to mammals only these functional aortic arches have persisted, although six pairs of aortic arches are usually reckoned as

the fundamental number. An idea of the changes involved from life in the water to life on land may be secured from the figure.



Fate of the aortic arches of the vertebrates as seen from the side. (After Guyer.)

The Course of the Blood in the Body

There are two distinct systems of circulation in the body. The *pulmonary circulation*, noted in connection with the study of the heart, takes blood from the right auricle and ventricle to the lungs, passing it back to the left auricle. The longer circulation is known as the *systemic circulation* in which the blood leaves the left ventricle through the *dorsal aorta* and through ever-branching arteries passes to the muscles, nervous system, kidneys, skin, and other organs of the body. It gives food and oxygen to these tissues, receives the waste products of oxidation while passing through the microscopic *capillaries*, and returns to the right auricle through veins.

Some of the blood on its way from the heart passes to the walls of the food tube and so on to its glands. From these parts it is sent with its load of absorbed food to the liver. Here the *portal vein* that carries the blood breaks up into capillaries around cells of the liver, which take out the excess sugar from the blood and store it as glycogen. From the liver the blood passes directly to the right auricle.

Functions of the Blood

The blood being the circulatory tissue plays a very important part in the maintenance of the organism. Most waste products of the tissues are carried by the blood from their point of origin to some other region of the body which is adapted for their elimination. Thus the nitrogenous waste, *urea*, is carried to the kidneys. Other wastes are eliminated through the sweat glands of the skin or the lungs. The blood stream is also concerned with the transportation of oxygen from the lungs, and nutrient material from the intestines to the tissues. In addition, it carries the products of one tissue to another; for example, internal secretions which are produced in glands must be transported elsewhere to do their work. *Secretin*, already referred to, will serve as an example of this type of action.

In addition to the three transportation jobs already mentioned the blood also serves to remove various waste products of metabolism from the point of their formation to the organs which excrete them, *i.e.*, the lungs, skin, intestines, and kidneys. Through its accessibility to the various organs and glands of the body, the blood may aid in maintaining the normal *acid-base* balance of the tissues as well as the water content of the body.

We know that oxidation generates heat, which means that in the human body heat is being constantly released by the working cells. It is carried by the blood stream to the outside layers of the body and there dissipated in the surrounding environment unless special heat-regulating devices are present. Man regulates his body temperature very largely by controlling the heat loss through nerve impulses causing contraction of the minute blood vessels in the skin. The expansion of these blood vessels, resulting from the stimulus of the *vasomotor center* of the *medulla oblongata*, allows greater radiation and consequent loss of heat (see page 351). What is of perhaps still greater importance to man in cooling his body is the ability of sweat glands to increase their action under proper nervous stimulation and to pass out more sweat to be evaporated. Heat is required

to vaporize the sweat on the body surface, and body heat is lost. Conversely, by performing muscular work, heat may be produced in greater quantity through the increase of oxidations in the body.

Clotting is another very important function of the blood. We are all familiar with the fact that while blood is fluid when drawn from the body it soon becomes viscous and later gelatinous. Finally a clot is formed, which may be seen floating in the blood serum. It was initiated in part by the dissolution products of the blood platelets. In the gelatinous stage, both red and white corpuscles are caught in the fibrin network, and as the clot shrinks the red cells are held more tightly by needlelike fibers of *fibrin*. There are too many theories of clotting to present here, but when blood is exposed to air chemical changes finally transform the soluble *fibrinogen*, which occurs normally in the blood stream, into insoluble *fibrin*. The blood of a normal person ordinarily clots in about five minutes. The blood of a few persons, however, forms clots very slowly or refuses to clot at all. Such a condition is known as *hemophilia*, and the person affected as a *hemophiliac*.

Finally, the blood plays an important part in health and disease both through the distribution of *antibodies* and the defense mechanism of the white corpuscles against bacterial invasion.

SECTION C. RESPIRATORY DEVICES

Respiration

Every living organism requires oxygen for its metabolic processes, which demands that every cell shall take in oxygen and give off wastes, largely carbon dioxide and water. This exchange of free oxygen and carbon dioxide is necessary for combustion. In all vertebrates respiration may be divided into two types, *external* and *internal respiration*. The former involves the exchange of gases between the atmosphere and the blood through some specialized device such as gills or lungs, while internal respiration is an interchange between the blood and the cells of the body.

In looking into the story of respiration, one finds the first relevant suggestions coming from John Mayo who in 1668 suggested that respiration and combustion were analogous processes. His work was antedated by another early worker, Robert Hooke, the same man who described the dead cells in cork, and who demonstrated by the use of experiments that air is necessary for the maintenance of life

in animals. It was Priestley (1733–1804), however, who discovered oxygen and recognized its great importance to all living matter. The name of one more important early worker, Lavoisier (1743–1794), should remain in our memory as he was the first man to attempt a quantitative scientific study of the phenomenon of respiration. It was he who first stated “life is a chemical action” and who realized that animal heat was the result of an oxidation process involving substances of the body. Both he and LaPlace (1749–1827) carried on numerous experiments on respiration and its relation to the production of animal heat. Out of this humble beginning has come all the later fascinating studies upon respiration by such workers as Liebig, Voit, Rubner, Pettenkofer, Atwater, Rosa, Benedict, and others.

The Protein, Hemoglobin

Before turning attention to the various devices developed to meet the problem of respiration one mechanism that is universally present in the vertebrates should be mentioned, namely, the respiratory pigment *hemoglobin*. This is a protein compound found in the red corpuscles of vertebrates. It has the ability of combining readily with oxygen to form *oxyhemoglobin*, thus enabling the blood stream to carry much more oxygen than it could possibly do by saturating the plasma.

The interchange of oxygen and carbon dioxide may be explained by physical laws. It is known that a gas tends to pass in the direction of the least pressure. Even when a moist, permeable membrane, or a selectively permeable membrane, such as the epithelium of the lungs and capillaries, is placed between different gases the molecules pass freely back and forth. In the event of a difference in pressure between the two sides of the membrane, the gases pass through from the region of greater pressure to that of the lower pressure until it is equalized. Oxygen constitutes nearly 21 per cent of the atmosphere and is present in sufficient amounts to furnish enough pressure to transfer it to regions of lower pressure. If we keep in mind the fact that the pressure of oxygen *outside* the body must always be greater than that in the blood stream in the lungs, we can readily understand why oxygen *must* pass through the moist permeable membranes and into the blood stream, thus giving us the explanation of *external respiration*. On the same basis *internal respiration* may be explained. The first step involves the liberation of oxygen from the blood to the lymph,

while the next centers around its transfer to the cells of the body. An examination of the first stage shows the blood passing through the capillaries which are bathed in lymph where the oxygen pressure is very low. This condition brings about dissociation of the oxyhemoglobin to such a degree that it loses over a third of its oxygen during its brief passage through the capillaries. The lymph in turn loses oxygen to the cells in the same way. While oxygen is being liberated carbon dioxide is being returned to the blood stream in exactly the same manner, for carbon dioxide is present in greater concentration in the cells than in the lymph and in the blood stream respectively.

External Respiration

While the phenomenon of respiration is a common one yet it is accomplished in many different ways. Small, single-celled, or relatively simple organisms have no need of a complicated respiratory system. However, it is well to remember that while the surface of a body varies as the square, its volume varies as the cube of its diameter. This means that as an object increases in size the ratio of its surface to its volume becomes smaller. By transferring this thought to biological fields we can readily appreciate that as animals increase in size respiratory systems become a real necessity.

A survey of the animal kingdom shows that organisms have met this need in a great variety of complex and sometimes rather peculiar ways. Four types of respiration are commonly found, namely, respiration through the *surface of the body*, by means of *gills*, *tracheae*, and *lungs*. Three other methods are less commonly found, namely, by means of *respiratory papillae*, *respiratory trees*, and *lung-books*.

RESPIRATORY PAPILLAE. These occur as evaginations from the dorsal surface of such forms as the starfishes, where they are known as *dermal branchiae*. They are really outpocketings of the body wall.

RESPIRATORY POUCHES OR TREES. These tubular and more or less branched pouches occur in such groups as the sea urchins, holothuroideans, and some starfish. In the first group the pouches are outgrowths from the mouth, while in the holothuroidea they are outpocketings from the rectal region (see figure, page 314).

LUNG-BOOKS. Such structures consist of a series of folds suggesting the pages of a book. Each "leaf" is filled with blood spaces and is exposed on two sides to the air. Respiratory devices of this type

are found in many spiders while a similar structure called a gill-book occurs in the horseshoe crab, *Limulus*. Gill-books may more

properly be considered as modified gills.

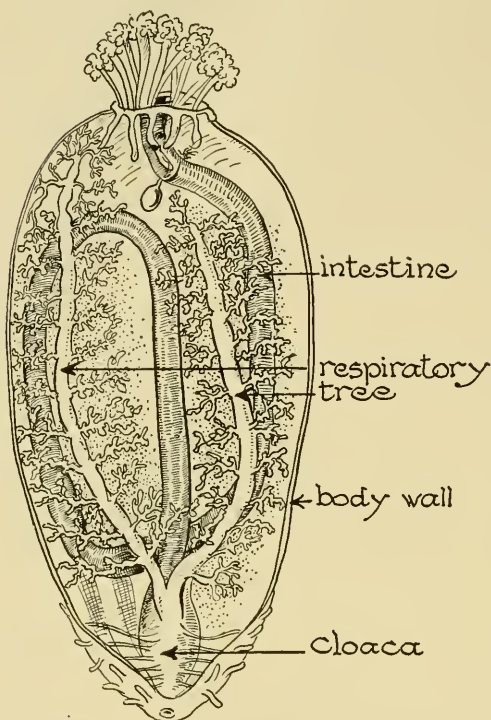
THE BODY SURFACE.

This type of respiratory system is probably the most simple. It consists of an exchange of gases through the surface of the body. It is found, however, not only in such simple one-celled animals as the protozoa, which have no specialized system for respiration, but also in sponges and coelenterates. Even in the parasitic and free-living, flat worms and some roundworms, respiration is of the same type. Some of the smaller forms of the higher groups may also resort to this method of gaseous exchange.

In some of the more highly specialized forms

such as the earthworms, a circulatory system is present although respiration still takes place through the cuticle. The blood of the earthworm is red and contains hemoglobin which is dissolved in the plasma, just the opposite of the situation in the vertebrates where hemoglobin occurs in the red blood cells.

Complete dependence upon integumentary respiration does not occur among vertebrates. Probably the closest approach to such a situation is in the lungless salamanders (Plethodontidae) and in certain other urodeles, such as the hellbender, *Cryptobranchus*. In the former, integumentary respiration is usually supplemented by a capillary network in the pharyngeal region and is therefore designated as *buccopharyngeal respiration*. A highly developed system of capil-



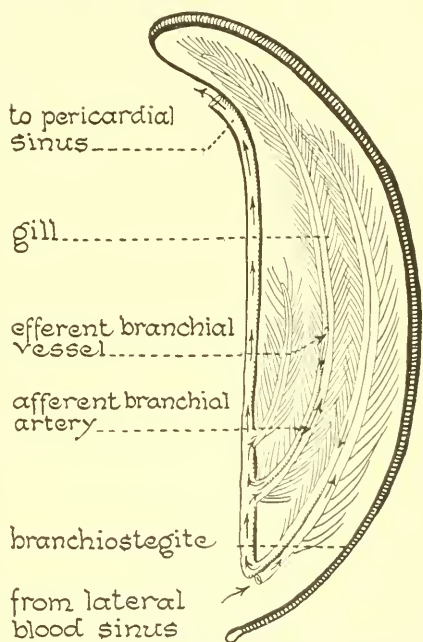
The "lungs," or respiratory tree of the sea cucumber, a holothurian.

laries which almost penetrate to the outer surface of the epidermis is found in the integument of many amphibians. In some amphibia as much as 74 per cent of the carbon dioxide is given off through the skin. Such adaptations are possible only where a cool environment keeps down the metabolic rate of these forms.

GILLS. Gills are either flattened or feathery, and are external or internal in their location. Invariably the blood circulates in them and is separated from the surrounding water by a thin membranous wall through which the dissolved gases are exchanged. Among the invertebrates the position of the gills varies in accordance with the habitat of the animal. In such forms as the crayfish for example, they are in a protected outer chamber covered by chitin. Circulation is accomplished by the creation of a water current through the action of the swimmerets and certain appendages about the mouth. In fishes and amphibians, water typically enters the mouth where it is passed to and over the pharyngeal gills and from there through slits to the outside.

TRACHEAE. These are composed fundamentally of air-carrying tubules, which, by a series of anastomoses and ramifications, penetrate to nearly all parts of the body. They are characteristically found in most

insects, myriapods, protracheates, and some arachnids. Such a system starts with a series of openings known as *spiracles*, occurring along the outer surface of the thoracic and abdominal segments. Leading from the spiracles are air tubes, or *tracheae*, which show great numbers of anastomoses, frequently forming abdominal reservoirs, or *air sacs*. The tracheae are nothing more or less than a series of pipes, for they are lined with chitin and stiffened by a spiral, fiberlike thickening. The finer subdivisions of the tracheae extend



Portion of gills of crayfish. Note the protecting branchiostegite. How is the blood aerated?

to all inner parts of the body where they end blindly making possible the delivery of oxygen directly to the cells. Here again *external respiration* takes place in the spiracular region, while *internal respiration* centers about the diffusion of gases to and from the tracheae and the cells. The efficacy of this system is suggested by the rapid and sustained metabolism common to many of the insects.

LUNGS. This type of respiratory system is found best developed among the birds and mammals. The lungs of birds are specialized for a high metabolic rate and for making lighter the load which must be lifted in flight. Air sacs connected with the lungs are found throughout the viscera, and even the bones are filled with air and so are very light. The connection between these and the rest of the respiratory system has been demonstrated by closing the trachea and opening the air sac in an upper wing bone. The fact that the bird continues to breathe demonstrates this connection.

The mammalian respiratory system is essentially the same regardless of the form studied. The most important part of the lungs are the terminal air sacs called *alveoli*, in which the inspired air contacts the many capillaries of the circulatory system found throughout the moist mucous membranes. Oxygen and carbon dioxide diffuse through the capillary walls surrounding the alveoli and so the exchange of gases is effected.

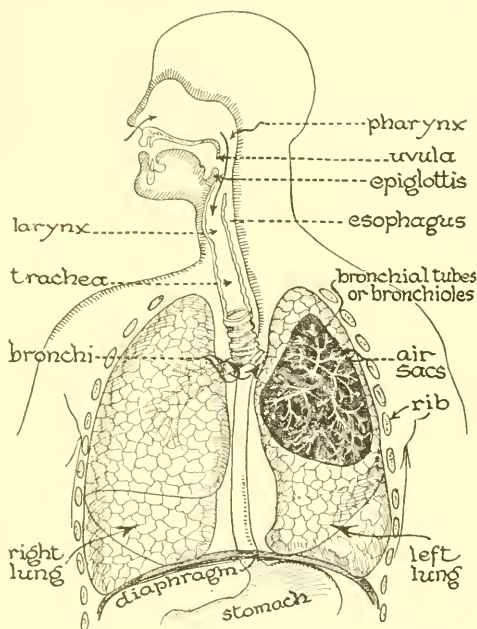
Internal Respiration

It has been shown in the case of very simple animals, such as *Paramecium*, that when oxidation of food takes place in the cell energy results. In forms which possess complicated circulatory systems, external respiration must first take place, after which oxygen is transported by the hemoglobin of the blood to the various parts of the body where the actual work is to be done. Here real or *internal respiration* takes place, since cell activity depends upon food and oxygen.

As aerated blood passes through the capillaries these are bathed in plasma in which the oxygen pressure is low. The oxyhemoglobin, a compound of oxygen and hemoglobin, is stable only in an environment where oxygen pressure is comparatively high. Therefore the hemoglobin delivers itself of the oxygen to the lymph, which in turn transfers it to the cells. The pressure of carbon dioxide on the other hand is higher in the cells thus facilitating its transfer to the lymph and so to the blood stream proper.

Respiratory System in Man

Air passes from the *nostrils* through the slitlike *glottis* into the windpipe. This tube, called the *trachea*, the top of which may easily be felt as the "Adam's apple" of the throat, is supported by a series of cartilaginous rings complete in front but incomplete behind and dividing into two *bronchi*. Within the lungs, the bronchi break up into a great number of smaller tubes, the *bronchioles*, which divide somewhat like the small branches of a tree and are lined with ciliated epithelial cells. The remainder of the tubes are also lined with ciliated cells, the cilia of which are constantly in motion lashing with a quick stroke toward the outer end of the tube, that is, toward the mouth. Hence any foreign material in the tubes will be expelled first by the action of the cilia and then by coughing or "clearing the throat."



The respiratory system of man. Note the cartilaginous rings supporting the ducts.

The bronchial tubes end, as already noted, in very minute air sacs called *alveoli*. Great numbers of these are present, thereby increasing the respiratory surface tremendously. These tiny pouches have elastic walls into which air is taken when we inspire or take a deep breath. Around the walls of the pouches and separated by a very thin membrane, are numerous capillaries from the *pulmonary artery* which brings the blood from the right ventricle of the heart to the lungs. Through the very thin walls of the air sacs a diffusion of gases takes place, which results in the blood giving up carbon dioxide and taking in oxygen. Consequently the blood becomes a brighter red, due to formation of *oxyhemoglobin* by the combination of oxygen with the hemoglobin in the red corpuscles.

COMPOSITION OF FRESH AIR AND THAT EXPIRED FROM THE LUNGS

CONSTITUENTS	IN OUTDOOR AIR	IN AIR EXPIRED FROM THE LUNGS
Oxygen	20.96	16.4
Carbon dioxide04	4.1
Nitrogen and other gases	79.0	79.0
Water vapor	variable	.5

As shown in the above table, there is a loss of nearly 5 per cent of oxygen and a corresponding gain in carbon dioxide and water vapor in expired air.

The lungs are located in a triangular, air-tight sac or *thoracic cavity*, with the sternum or breastbone in front, the ribs on the side, the immobile vertebral column at the back, and the convex diaphragm below. The ribs, connected to the breastbone in front and the backbone behind, are united to each neighboring rib by a sheet of *intercostal muscles*. Furthermore the articulation of the rib with the vertebral column is higher than its connection with the sternum, and the shape is such that when the lungs are empty the "convexity of the curve points slightly downwards." Inspiration results from the contraction of the intercostal and associated muscles which not only pull the ribs toward a horizontal position but also force the sternum ventrally. The *diaphragm*, which also assists, is a combination of a membrane and muscle and forms a partition between the thoracic and abdominal cavities. The concave surface of the diaphragm is towards the posterior, that is, down. Contraction reduces the concavity so that the result is an increase in the capacity of the thoracic cavity. Keeping in mind that the chest cavity is air tight, the lungs elastic, and that the sole entrance of air is from the trachea, it is not difficult to see that when the capacity of the chest cavity is increased by the movements described above, the lungs naturally expand and *inspiration* takes place. *Expiration* is produced in part by special muscles, the relaxation of the diaphragm and walls of the chest cavity, and the elasticity of the lungs themselves.

The nervous mechanism that controls this process is found in the *respiratory center* of the *medulla oblongata* (see page 351.) Under normal conditions respiration results from the alternate stimulation of two sets of fibers in the *vagus nerve* leading from the lungs to the respiratory center. The *inspiratory fibers* are stimulated at each expiration by the collapse of the lungs, which results in an increase in

the rate of inspiratory discharge from the center down the cord to the various levels where the relay apparatus or sympathetic system causes inspiration. As the inspiration occurs the *expiratory fibers* of the vagus are stimulated by the expansion of the lungs and the inspiration is partially inhibited. Experiments clearly indicate that the gases in the blood have a direct effect upon the activity of the center since, for example, an increase of carbon dioxide in the blood results in an increase in the force or rate of the respirations. This however does not tell the whole story. Recently accumulated data furnish evidence for the belief that the activity of the respiratory center is controlled by the hydrogen-ion concentration of the blood passing through it, which in turn is affected by the pressure of carbon dioxide in the blood.

SECTION D. EXCRETORY MECHANISMS

Excretion

This term is used to cover the separation, collection, and elimination of the waste products of metabolism from the body. These waste products naturally vary within the organism itself from time to time, and show even greater variation between different species of animals. Fundamentally such devices center about mechanisms which are adapted in different ways for the elimination of one fundamental by-product — *nitrogenous wastes*. In addition liquids in the form of water, dissolved inorganic salts, and *gases*, as, for example, carbon dioxide, are likewise eliminated by excretory devices. Likewise the digestive tract furnishes the avenue through which solid wastes may be eliminated, although this latter method should not be regarded as true excretion. Furthermore it should be realized that, in the vertebrates at least, there is a constant elimination or sloughing off of the exposed cells on various epithelial surfaces, as well as from the linings of various tubes and ducts which connect more or less directly with the outside. This section, however, is primarily concerned with the various urinary devices for the disposal of liquid wastes.

In highly specialized forms such as mammals a number of devices are adapted in one way or another for the elimination of waste products. Before studying these mechanisms in any detail, we shall consider briefly the various types of excretory systems found throughout the animal kingdom.

Types of Excretory Devices

CONTRACTILE VACUOLES. Protozoa are usually characterized by some sort of *contractile vacuole* which serves to eliminate such substances as carbon dioxide, surplus water, and perhaps some non-volatile nitrogenous substances. In addition to contractile vacuoles, protozoa may store and later eliminate more solid wastes by the formation of granules or crystals within vacuoles in the body.

INTRACELLULAR EXCRETION. In some of the simplest metazoa a so-called *intracellular excretion* takes place. This involves the ingestion of particles of waste products by certain ameboid cells which leave the body and disintegrate, freeing the excretory matter within their protoplasm. Associated with this process is the excretion of other wastes from the surface of the body, as is characteristic of some of the sponges. In addition, certain cells may store waste products or there may be localized areas for excretion.

OTHER EXCRETORY DEVICES. In some of the coelenterates the first evidence of true excretory organs appears in the form of pores connected with the alimentary tract through the canal system (*e.g.*, Hydra and Discomedusae). Although other types exist they are unimportant for our purposes and may be omitted.

Among slightly higher forms than sponges and coelenterates the waste products are carried to the outside through a complicated system of connecting tubules in which are located occasional ciliated cells, whose function appears to be to keep the fluids in motion. The blind ends of these tubules are capped by minute ciliated cells of the protonephridial excretory system called *flame cells*. These lie in the parenchyma and by their movement initiate the flow of liquid and soluble waste products which they have secreted through the wall. The waving of the tuft of cilia in each cell is responsible for the introduction of the term *flame cell*. In some cases it is believed that the cells of these convoluted tubules may also reabsorb food material from the passing "wastes" as well as contribute excreta to the stream.

Reaching the higher segmented worms like the earthworm, the excretory apparatus is composed of a system of paired *nephridia* for each somite. Such nephridial systems are really a series of separate units, each of which is composed of a ciliated funnel, or *nephrostome*, and a duct that passes through the posteriad septum to empty to the outside. A portion of the canal is usually glandular or secretory in function and serves to discharge waste products into the tubule and

possibly to reabsorb any nutrient materials which escaped in wastes from the fluid in the body cavity (see figure, page 192).

In the insects still another type of excretory system is composed of special tubules called *Malpighian tubules*. The cavity of each tubule is surrounded by large cells covered by a peritoneal lining, emptying into the intestinal canal. The free ends of the tubules lie in the body cavity, where they are bathed in blood. The waste products pass into the Malpighian tubules from the blood. This interpretation is supported by the detection of considerable quantities of nitrogenous material in the tubules (see figure, page 210).

Excretory Devices of Vertebrates — Kidney

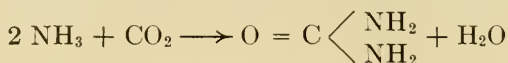
The excretory organs of vertebrates are known as *kidneys*. While several different forms of kidneys are known to exist, they are all derived embryologically from paired segmented structures, which in many of the lower types may be connected with the body cavity by a series of ciliated funnels reminiscent of the earthworm. Along with the complex changes of the various systems of organs found in the higher forms, especially of the circulatory system, there is a much more intimate association of the circulatory and excretory systems and a decrease in the importance of the part played by the body cavity in the removal of wastes.

The Mammalian Excretory System

A typical mammalian excretory system is a complex affair, for it involves not only the kidneys and their associated ducts, but also the bladder and portions of the circulatory system as well. This does not tell the entire story, for the liver, lungs, skin, and alimentary tract also play an important part in the excretion of wastes.

THE LIVER. The liver, which was considered in connection with the digestive system, also plays a vital rôle in the elimination of certain wastes from the body. Proteins are absorbed from the digestive tract in the form of amino acids. Too heavy a protein diet results in the absorption of more nitrogen-containing material than can be utilized by the cells of the body for tissue building. The cells of the liver have the ability to split off the nitrogen-containing radical and in some instances resynthesize the remaining materials to carbohydrates and even fat. The nitrogen which is thus left behind may have been removed as ammonia (NH_3) which is quite toxic to the

body, especially the nerve centers, but the liver also splits off hydrogen and unites it with carbon dioxide to produce a relatively harmless substance called *urea* ($\text{CO}(\text{NH}_2)_2$), and water, thus



which in turn is removed from the blood stream by the kidneys. Other products which are eliminated by the liver include bile, its pigments, as well as various salts, neutral fats, cholesterin, and lecithin.

OTHER DEVICES FOR WASTE ELIMINATION. There are parts of other systems that should be mentioned in a consideration of the phenomenon of excretion. These are the lungs, skin, and alimentary canal. The former, as previously noted, excretes through the alveoli most of the carbon dioxide produced in the body of man. This may be indicated in tabular form ¹ for man as follows:

ORGANS	ESSENTIAL	INCIDENTAL
Lungs	Carbon dioxide	Water, heat
Kidneys	Water and soluble salts, resulting from metabolism of proteins, neutralization of acids, etc.	Carbon dioxide, heat
Alimentary canal . .	Solids, secretions, etc.	Water, carbon dioxide, salts, heat
Skin	Heat regulator	Water, carbon dioxide, salts, hair, nails, and dead skin

The skin serves a variety of purposes, one of the most important being regulation of the elimination of small amounts of carbon dioxide. When the kidneys are not functioning properly the skin may be stimulated to excrete more waste substances. The alimentary canal serves to rid the body of nondigested and nondigestible substances which, through the processes of digestion, have yielded up their content of foods. Furthermore, the alimentary canal actually excretes waste products through its walls into the lumen of the canal.

THE KIDNEYS. We think of these structures as the principal organs of excretion, and perhaps rightfully so. Nevertheless elimination of wastes is not the only important function of the kidneys. They help

¹From Kimber, Gray, and Stackpole, *A Textbook of Anatomy and Physiology*. By permission of The Macmillan Company, publishers.

to keep the ingredients of the plasma of the blood standardized, thus regulating the salt content of the blood by altering the ratio of salt to water produced in the urine, depending upon the amount taken into the body. The normal healthy person eliminates the following amounts of waste per day, through the kidneys: 30 grams of urea (converted ammonia); 15 grams of urea salt; 10 grams of other soluble urea substances. The remainder, 96 per cent by weight, is water, making a total of one to one and a half liters that is eliminated.

A sagittal section through the kidney reveals the expanded upper end of the *ureter* on the median side draining the basinlike *pelvis* of the kidney. The outer portion is a compact region called the *cortex*, while the inner striated portion ending in the irregular margin of the *pelvis* is known as the *medullary substance* of the kidneys.

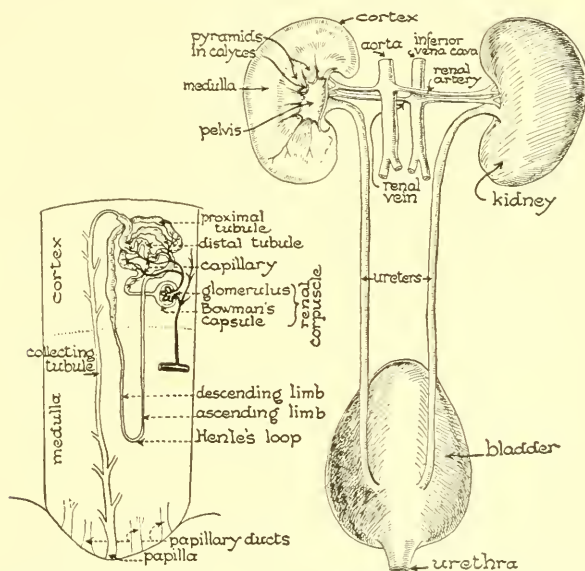


Diagram of the human excretory system. How do urea, water, and inorganic salts reach the pelvis?

The inner margin of the medullary substance forms *renal pyramids* the tips of which are projections, or *papillae*, that lie in closely investing cuplike depressions of the pelvis, called *calyces*. The tip of each papilla is dotted with the openings of the collecting ducts, which in turn are formed from the union of several *renal* or *uriniferous tubules*.

These uriniferous tubules begin in an expansion (*Bowman's capsule*) about a little arterial knot of capillaries, called a *glomerulus*, which together make up the functional unit of the excretory system, known as a *renal* or *Malpighian corpuscle*. In order to understand the workings of these million odd excretory units, it is necessary to understand the anatomy of the kidney.

The main trunk line of the arterial system gives off a pair of renal arteries that are broken down into many very small *afferent vessels* each of which enters the glomerulus, leaving as a smaller *efferent vessel* that breaks down into a typical capillary network over the convoluted surface of the tubule. As the wall of *Bowman's capsule* surrounding the glomerulus is thin, it is believed that water and inorganic salts are mechanically filtered out into the cavity by means of differences in pressure between the blood vessels and the lumen of the tubule. In the second set of capillaries the urea and other specific urinary constituents are first transferred by the cells and so secreted in the uriniferous tubule. Water and certain salts are reabsorbed into the blood stream at this point.

In any event, the kidneys remove the waste products from the blood stream, transferring them to the pelvis of the kidney, and thence down the *ureters* to the bladder. Here the urine is stored until finally released to pass to the outside through the *urethra*.

SUGGESTED READINGS

Clendinning, L., *The Human Body*, Alfred A. Knopf, Inc., 1930. Chs. III-VII.

More popularized anatomy and physiology.

Haggard, H. H., *Devils, Drugs, and Doctors*, Harper & Bros., 1929. Ch. VI.

A popular account of early anatomy and physiology.

Howell, W. H., *Textbook of Physiology*, 17th ed., W. B. Saunders Co., 1933.

Chs. XXIII, XLI, XLII, XLIII, and XLV.

A detailed, technical account of physiology.

Kimber, D. C., Gray, C. E., and Stackpole, C. E., *Textbook of Anatomy and Physiology*, 9th ed., The Macmillan Co., 1934. Chs. XVII and XXI.

An anatomy and physiology of the human respiratory system. Technical but condensed.

Loey, W. A., *The Growth of Biology*, Henry Holt & Co., 1925. Ch. X.

An account of Harvey's contribution to our knowledge of the circulatory system. See also other books by this author, or others on the history of biology.

Metcalf, C. L., and Flint, W. P., *Fundamentals of Insect Life*, McGraw-Hill Book Co., 1932. Chs. III and IV.

A brief account of insect anatomy and physiology.

Pearse, A. S., and Hall, E. G., *Homoiothermism*, John Wiley & Sons, Inc., 1928.

An interesting discussion of the origin of warm-blooded vertebrates.

Plunkett, C. R., *Outlines of Modern Biology*, Henry Holt & Co., 1930. Ch. V.

A good physico-chemical account.

Rogers, C. G., *Textbook of Comparative Physiology*, McGraw-Hill Book Co., 1927. Chs. XVI, XVII, XXII, XXIII, and XXVII

An advanced account of physiological digestive processes from a comparative viewpoint.

Wells, H. G., Huxley, J. S., and Wells, C. P., *The Science of Life*, Doubleday, Doran & Co., 1934. Ch. II, Sec. 7, Book 1; Ch. II, Secs. 4, 5, and 6.

A readable, popular account.

XVI

SUPPORT, MOTION, AND SENSATION

PREVIEW. *Section A.* Skeletal devices · The interdependence of parts · The kinds of skeletons: Exoskeletons; endoskeletons; the axial skeleton; the appendicular skeleton · Functions of skeletons: Support; protection; movement · *Section B.* Devices for movement · The “why” of motion and locomotion; protoplasmic extensions; dermo-muscular sacs; water vascular systems · Muscles and muscular systems: Smooth or involuntary muscles, skeletal or striated muscles, heart muscle, muscular contractions · *Section C.* Mechanisms of sensation and co-ordination · The morphological unit — The neuron · The physiological unit — The reflex arc · Types of nervous systems: Neuromotor mechanisms; co-ordination by a network; co-ordination by a nerve ring; co-ordination by a linear nervous system; co-ordination by a dorsal tubular nervous system · Protective devices for the central nervous system · Anatomy and development of the brain: The early development of the central nervous system; the parts of the vertebrate brain: The cerebrum or telencephalon, the Twixt-brain or diencephalon, the mid-brain or mesencephalon, the cerebellum or metencephalon, the medulla oblongata or myelencephalon · The cranial nerves · The spinal cord · The spinal nerves · The autonomic nervous system · The sense organs — Receptor devices: taste; smell; simple light receptors; compound eyes; camera eyes; ears; cutaneous sense organs · Suggested readings.

PREVIEW

It will be seen from the preceding unit that one of the most important essentials for an animal is to carry on successfully its metabolic processes. This is equally necessary for plants although they have the advantage of being able to secure most of the raw food materials they need from their immediate environment. Animals have to move to get their food. The necessity for motion involves three factors, a mechanism to support the body when seeking food, machinery to do the moving, and an apparatus to detect the location of food. In order to locate food, a co-ordination of eye and limb under control of the nervous system is required. The eye receives a stimulus the instant that the color or shape of food is noted by the receptor devices in the retina. The motions of the arms and legs then supplement the desire for food, followed by the act of taking it. In

this triple process some of the thousands of pressure endings that are scattered over the body come into play. Many of these, in the case of man, are conveniently concentrated in the finger tips which relay messages to the brain. It is readily seen that the process of getting food requires co-operative action of the skeletal, muscular, and nervous systems.

The limb action involving stooping, standing, and reaching calls into play different sets of voluntary or skeletal muscles. This emphasizes one of the fundamental principles of the study of muscles (*myology*), namely, that for every muscle group there is an opposing set which performs the opposite type of movement. Muscles are effective during contraction and not during relaxation. We speak of the muscles that extend the arm or leg as *extensors* and those which bend them as *flexors*. Such muscles are very different from the smooth, involuntary muscles in the walls of the intestines. Here the food undergoes rhythmic segmentation and is broken up into boluses by the intermittent contractions of smooth muscle cells. Fortunately, the control of these involuntary muscles is taken off the hands of the voluntary or central nervous system. Such routine functions are put under the control of the autonomic nervous system, which frees the brain of the necessity of "willing" all these things to happen and leaves the central nervous system free for "higher evolutionary adventures" by taking over the "drudgery of living." In order to understand these processes, commonly taken as a matter of course, we must investigate carefully the "why and how" of locomotion and then try to see how this complicated performance is controlled.

SECTION A. SKELETAL DEVICES

The Interdependence of the Parts

The material covered in this unit consists of representatives of three well-defined and anatomically separable systems, namely, the skeletal, muscular, and nervous systems. Although they are frequently considered separately for the sake of clearness it should be kept in mind that, physiologically, the muscles, skeleton, nerves, and blood supply are all intimately interwoven. In the human body, there are numerous muscles most of which are under voluntary control and as such are concerned with posture, with maintaining the relationship of the various skeletal parts to one another, or with some sort of movement.

All of these muscles are under the control of the nervous system, while energy for their continued movement must be furnished by means of absorbed food transported through the circulatory system to every part of the body. To visualize this inter-relationship think of the sustained movement of an arm or leg which is dependent upon the activity of numerous muscles. The action of the muscles is in turn controlled by the nerves which conduct messages to the tissues from the brain and spinal cord. The entire network of nerves and their branches has often been likened to a telephone system with its complicated series of connections and relay wires. Closely associated with the nerves are the arteries and veins, forming the triumvirate so often pictured in histological or medical texts.

The Kinds of Skeletons

Skeletal support is of common occurrence in the animal kingdom. Skeletons may be divided typically into outer coverings, or *exoskeletons*, and inner supporting devices, or *endoskeletons*.

Exoskeletons

Generally speaking, any creature or organism possessing *only* an exoskeleton belongs to the large group of invertebrate, or non-chordate, animals. Such forms may be present in some members of a given phylum and not in others. Even in the protozoa, for example, the shelled *arcellidac* occur in the same class with the naked *Ameba*. Other examples within this same group are the *foraminifera* and *radiolaria* which possess limy or glassy skeletons. This suggests that on the whole these types of exoskeleton are not essential for locomotion but are primarily protective devices. That is certainly true of the sessile sponges, corals, sea-lilies, and lamp-shells (*brachiopoda*), and would also probably hold for most of the clams, snails, star-fishes, and brittle-stars. In the great phylum of the arthropods, the exoskeleton is specialized and definitely associated with an equally highly adapted muscular system, the two being definitely designed for effecting locomotion. Even among the vertebrate chordates an exoskeleton as well as an endoskeleton sometimes occurs, as, for example, in the turtles. In such forms the vertebral column becomes fused to the dorsal shell which is formed by the flattened ribs plus dermal *costal plates*.

Endoskeletons

Endoskeletons are characteristic of chordate animals. An internal supporting rod (*notochord*) is clearly present in the larvae of the tunicates and in the adult amphioxus, while a well-developed endoskeleton is found in all of the so-called higher forms from fishes to man.

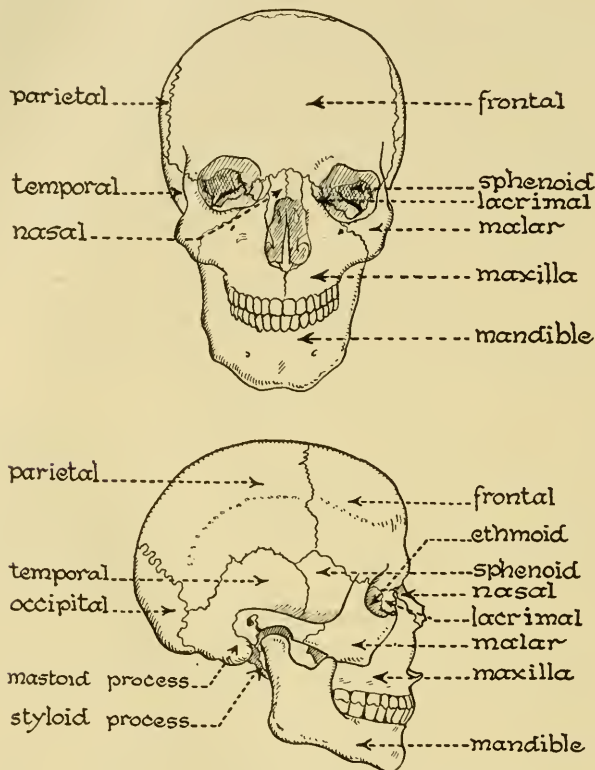
The skeleton of vertebrates is divided typically into three parts: the *axial skeleton*, which includes the skull, thoracic basket, main spinal column, and tail; the *appendicular skeleton*, which pertains to the appendages; and the *visceral skeleton*, which is developed in connection with the various modifications of the gill region. In adult fish, the visceral skeleton forms the cartilaginous or bony bars (*gill arches*). In other vertebrates, the visceral skeleton becomes converted into various highly modified structures involved in the formation of the jaws, the hyoid support of the tongue, the larynx, accessory parts of the skull, and even the bones in the middle ear.

The Axial Skeleton

Anteriorly, the axial skeleton of vertebrates is specialized into a *skull*, a bony case covering the expanded anterior end of the spinal cord, or brain. Incorporated into this skull are specialized protective capsules for several of the major sense-organs, namely, the eyes, ears, and nose.

Many bones are fused to form the skull. These are of two sorts, either *membranous* or *cartilaginous*. The former are developed directly from a connective tissue membrane, while the latter type pass through a preliminary cartilaginous stage before becoming bone. In primitive vertebrates, the brain is protected by cartilage which later in the evolutionary picture becomes ossified. Still later, this original cartilaginous cranium is further protected by the addition of a group of thin, flat membrane bones, shingled over the skull. In higher forms the number of embryonic bones in the skull has been reduced. The skull of a dog, for example, contains fewer bones than that of a codfish. A study of the earlier stages of development in mammals shows, however, that representatives (or homologues) of many of the bones present in the cod skull may be found. These embryonic elements fuse in later development, making the smaller number of skull bones found in the adult. In the skull of a reptile, for example, there are four occipital bones surrounding the point of exit of the spinal cord from the skull, which in most adult

mammals are fused into a single *occipital bone*. Further study of a series of forms from fish to man would furnish remarkable evidences of homology besides emphasizing the interpretative importance of the study of *comparative anatomy*.

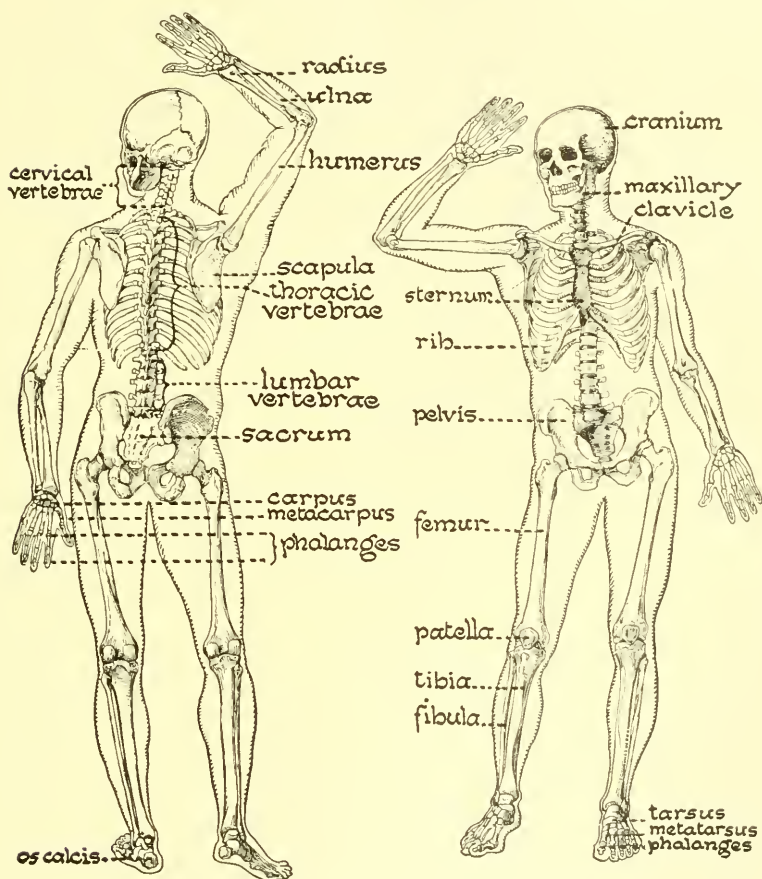


Bones of a human skull. (After Walter.)

The skull bones of man are frequently divided into *cranial bones*, which surround the brain itself, and those which are designated as *facial bones*.

The remainder of the axial skeleton is composed of the vertebral column and its associated bones. In aquatic forms like the fishes, this part of the axial skeleton is comparatively unspecialized, being divisible into the rib-bearing *vertebrae* of the trunk, and those without ribs, called *caudal vertebrae*, which go to make up the tail. With the evolution of land animals, protection of the under side of the body became essential and therefore a "thoracic basket" was de-

veloped, composed of ribs attached to a ventral breastbone (*sternum*) and to the dorsal backbone. Ascending the evolutionary tree farther the organism became better adapted to turn the head. A fish or frog must not only roll the eyes but also change the entire position of the body in order to look behind. Not so with a cat, which may



Human skeleton. Can you recognize the bones of a disarticulated skeleton?

roll its eyes and is also able to turn its head. This ability to rotate the head is due to varying numbers of *cervical*, or neck, vertebrae. Four-footed animals are further characterized by four other sets of vertebrae, *thoracic* (with ribs), *lumbar* (without ribs), *sacral* (for the attachment of the pelvic girdle), and *caudal*.

The Appendicular Skeleton

A study of any group of land animals shows a fundamental similarity of limb construction. Even such apparently diverse structures as the flippers of a whale or a seal and the wings of a bird are found to be identical in fundamental plan. All sorts of land animals typically possess shoulder and hip girdles, respectively known as *pectoral* and *pelvic girdles*. These girdles are attached directly or indirectly to the axial skeleton, thus providing rigidity and facilitating movement of the appendages. It is significant that the pentadactyl limb of the

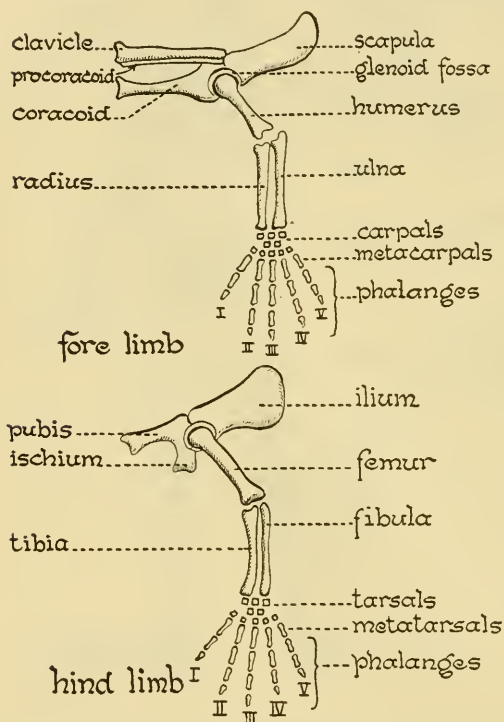
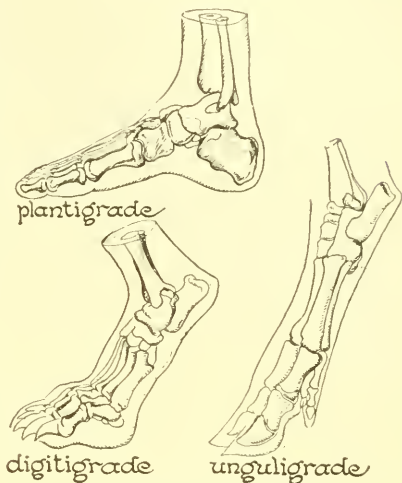


Diagram of the bones of the fore and hind limbs arranged to show their homology.

land vertebrates is built upon a generalized plan, in which each girdle is formed of three bones. Each front and hind leg is likewise composed of three major bones. In the anterior limb, a single *humerus* articulates with two bones, the *ulna*, a process of which forms the "funny bone" of the elbow, and the *radius*. In the posterior limb the corresponding bones are the *femur*, which is typically characterized by a prominent "ball" at one side of the main axis fitting into a socket in the pelvic girdle; the *tibia*, or shin-bone; and the smaller *fibula*. In addition to these larger bones is the group of wrist (*carpal*) and ankle

(*tarsal*) bones, followed by the *metacarpal* and *metatarsal* bones, depending upon whether they belong to the anterior or posterior limb. The bones of the fingers or toes are technically known as *phalanges*.

The feet of animals show many remarkable adaptations. Foot posture involves more than fallen arches; it determines the speed at which an animal can travel. If the wrist and ankle are raised from the ground the result is a longer leg capable of a longer stride, which means covering more ground in the same interval of time. Anatomists distinguish three types of feet: *plantigrade*, the primitive flat-footed type found in man and the bear; *digitigrade*, characteristic of cats or dogs that are literally "on their toes" all the time; and the *unguligrade*, restricted to forms which walk on their nails, like horses, cows, and camels.



Types of mammalian feet. State the advantages and disadvantages of each type of foot. (After Pander and D'Alton.)

Functions of Skeletons

Skeletal devices usually serve one of three functions, namely, *support*, *protection*, or *movement*. Examples of each type will be given, although it is sometimes difficult to separate these functions.

Support

It is quite apparent that organisms living in water have much less necessity for a supporting framework than land-inhabiting animals. This is due to the fact that the body approximates more closely the density of the surrounding medium and is consequently buoyed up by it. Cuttlefishes and jellyfishes maintain their shape in their natural environment but out of water collapse more or less completely.

In like manner, the bivalve shells of clams and mussels form a supporting skeleton, to which is attached the mantle that in turn encloses the viscera. Crayfish and lobsters offer still another example of skeletal support, for their movement is largely brought about through the interaction of a well-developed exoskeleton and inside muscles.

In land-inhabiting forms, the function of the skeleton as a supporting device becomes most apparent. It is hard to envisage any

other form of mechanical supporting mechanism which would permit the general physiological setup as we know it in land animals today.

Protection

It is difficult to speak of the skeleton without associating it with the idea of protection. Special devices suggestive of protection are scattered throughout representatives of most of the phyla. Certain types of spicules in the sponges, the calcareous exoskeleton of stony corals, and the thickened horny layer of other branching colonial coelenterates (hydroids) probably serve for the protection of these animals. Skeletal protective devices are also quite obvious in snails, starfishes, sea-urchins, arthropods, armored fishes, fossil armored reptiles, and turtles.

Movement

Movement is one of the almost universal characteristics of animals. Even in the protozoa special locomotor organs such as pseudopodia, flagella, and cilia are found. The earthworm uses its setae in crawling.

The greatest use of the skeleton for movement, however, occurs in the arthropods and vertebrates, two highly specialized groups. The former have well-developed exoskeletons while the latter are characterized by an endoskeleton. This means that in the case of insects, for example, the muscles are *inside* the skeleton while in vertebrates they are *outside*. In both groups, however, the skeletal elements articulate with one another, usually by means of curved and rounded surfaces permitting free movement of one part upon the other.

SECTION B. DEVICES FOR MOVEMENT

The "Why" of Motion and Locomotion

In the first place, animals must actively seek food and must be constantly on the move if they are to keep from starving. In addition, many animals, especially the higher vertebrates, give evidence of enjoying play, another type of muscular activity. This is more apt to be true of the young, but is also characteristic of many adults. If an organism is to survive in the struggle for existence, the ability to become adapted to different environments by moving from one place to another is a third essential. For example, grazing ani-

imals must be able to go from one feeding area to another. This holds good not only from the standpoint of competition for food but also from that of avoiding unfavorable climatic conditions, such as drought, which destroys those animals that are unable to keep on moving to a better feeding ground. Other animals use this same ability of movement in flight and so survive by being able to escape capture. Lastly, the part played by motion in perpetuating species should be mentioned. The strutting and bowing of a male pigeon, or the battle between two male deer in the silence of the forest are common examples of movement employed in the perpetuation of the species.

Protoplasmic Extensions

The concept of movement is usually associated with the contraction of muscles, but muscles do not tell the whole story. Three distinct types of locomotor devices — namely, pseudopodia, flagella, and cilia, which are so characteristic of the protozoa, have already been described.

The *cirri* of protozoa are probably the most highly specialized of all unicellular motile structures as they may be moved in any direction. Certain organisms like *Stylonychia* or *Euplotes* actually walk or run on the tips of their cirri. The action of the cirri is thought by some to be controlled by a so-called “neuromotor apparatus” present in these “simple” one-celled organisms.

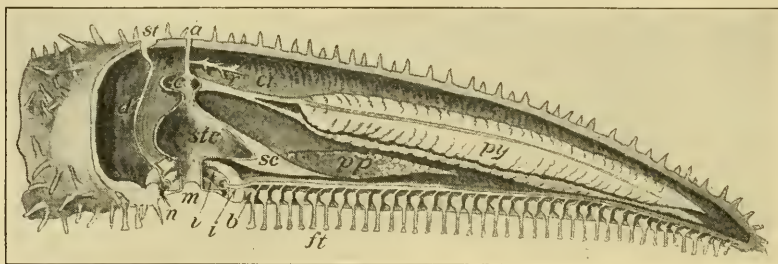
Dermo-Muscular Sacs

Many of the soft bodied invertebrates possess locomotor muscles concentrated in the outer layers of the body. The earthworm is an example of such a type. The body is shortened by the contraction of the inner longitudinal muscles and elongated by the action of the outer circular set lying immediately beneath the cuticula and hypodermis.

Water Vascular Systems

The echinoderms have exclusive patents on this method of locomotion that functions by means of water pressure in their numerous tube-feet. The apparatus opens on the dorsal surface of a starfish, for instance, through a sievelike structure, called the *madreporite*. Sea water may be added to the so-called *ambulacral fluid* through the

madreporite by means of cilia which send it along the *stone canal*. The latter structure leads straight down to the *circumoral ring canal*. Five *radial canals* branch from this and extend down the five arms sending off smaller branches which end in the tube-feet lying along the ambulacral grooves. The proximal end of each foot has a muscular



Vertical section through an arm of a starfish: *b*, ampulla; *d*, water canal opening at madreporite plate, *st*; *i*, radial water tube; *m*, mouth; *ft*, tube feet; *py*, digestive gland; *stc*, stomach; *a*, anus; *v*, ring canal; *n*, nerve ring.

bulb, the *ampulla*, which is capable of contracting, thus forcing the ambulacral fluid into the tube-foot. When the sucking disks at the free end of the distended tube-feet become attached to an object, the muscles of these tubular organs contract, forcing the water back into the ampullae, and the animal through its grip is enabled to move forward.

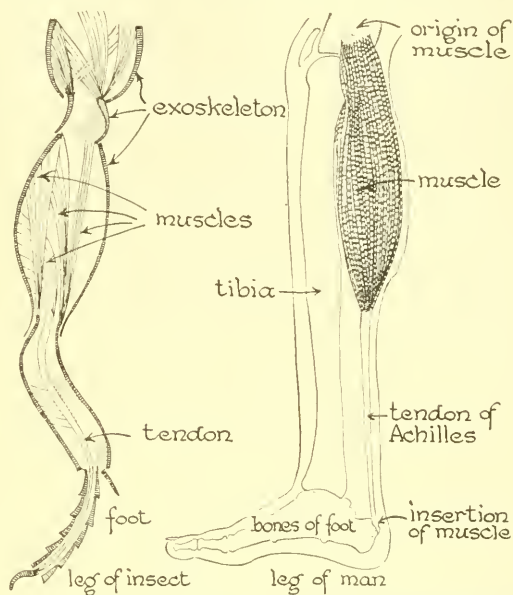
Muscles and Muscular Systems

Great differentiation of muscles is invariably related to a well-developed skeletal system. In two large diverse groups of animals, the arthropods, with a chitinous exoskeleton, and the vertebrates, with a calcareous endoskeleton, individual muscles rather than muscle layers have been developed. Examples of exoskeletal muscles are the colorless, transparent, or yellowish-white muscles typical of the insects. Although soft and almost gelatinous in appearance, these muscles which are usually striated are very efficient, as may be seen in the common house fly whose wings beat over 300 strokes per second. Among vertebrates there are found *smooth* or involuntary muscles, *skeletal* or striated muscles, and *heart* muscles.

While the muscles of a frog and those of a man may be homologous, that is, comparable embryologically and morphologically, it does not necessarily follow that they are analogous, that is, alike in

the particular function which they perform. The frog's leg, for example, is relatively incapable of more than a flexing motion or a straight swing of the limb, whereas the human arm responds to flexing, rotating, or swinging, according to the way in which it is moved. Human musculature is much more complex than that of a frog because it has many more diverse functions to perform.

Evidently there is a definite relationship between the types of motion which are possible from the standpoint of skeletal structure and the development of muscles that make such movements effective. Actual movement results from the contraction of muscles and is stimulated into activity by nerves. Since the muscles, nerves, and skeleton are closely correlated parts, their degree of usefulness depends to a marked degree upon the proper development and functioning of all the parts.



Comparison of the arrangement of the muscles and supporting skeleton of an insect's and vertebrate's leg. (Former after Berlese.)

SMOOTH OR INVOLUNTARY MUSCLES. This tissue is characterized by the absence of striations and the presence of a single nucleus in each cell or fiber. It is the type of muscle which carries on most of the internal movements of the body. The walls of the intestines are lined by layers of *circular* and *longitudinal* involuntary muscles. The muscles in the walls of blood and lymph vessels, the tracheal tube, reproductive ducts, the ureters, and the skin are also of this type. Typically sluggish in contraction, they are the principal kind of muscles found in the lower animals.

SKELETAL OR STRIATED MUSCLES. In this category fall all of the muscles which are under the control of the central nervous system and

which move the bones of the skeleton. There are approximately over five hundred such muscles distinguishable in man. They form the body wall, thus constituting, through a three-ply arrangement, the chief means of keeping the viscera in position. They regulate the position of the head and the degree of curvature of the backbone, as well as the shape of the thigh and the calf of the leg, and the contour of the arm. Since these muscles are responsible for all quick, considered movements, as well as simple reflex actions, they must be built upon a plan whereby one set of muscles through contraction may perform an opposite type of movement from the other, that is, work in opposition to each other.

Individual skeletal muscle fibers may reach something over an inch in length, but average only about $\frac{1}{500}$ of an inch in diameter. If a single fiber of skeletal muscle is examined under the microscope, the regular rows of striations become visible. Careful study reveals a series of dense strands of protoplasm running the entire length of the muscle fiber, between which are spaces filled with a watery protoplasmic material. It is believed that these delicate protoplasmic strands are capable of forcible contraction which, by mass action, results in the shortening of the entire muscle fiber. Each muscle fiber is enclosed in a modified elastic connective tissue membrane called *sarcolemma*, that bears scattered nuclei on its inner surface. Practically every muscle fiber cell is stimulated by a nerve ending. Groups of these muscle fibers are bound together with connective tissue, numbers of these bundles forming the muscle proper, which is then spoken of as a biceps, triceps, and so on.

The ends of a muscle are usually tapered. One end is anchored to an immovable portion of the skeleton, and is termed the *origin*, while the opposite end, which is attached to the portion of the skeleton to be moved, is termed the *insertion*. The *belly* of a fusiform muscle is the mid-portion between origin and insertion which swells during contraction. The tough sheath of connective tissue surrounding the muscle becomes continued as a *tendon* merging into the *periosteum* of the bone, thus giving a firm attachment. Striated muscles are also arranged in flat, fan-shaped masses, or in thin sheets.

HEART MUSCLE. This variety of muscle occurs in all of the higher animals. Although it has characteristics similar to the muscles previously described, cytological and physiological differences place it in a category by itself. Notwithstanding the fact that the action of the heart is involuntary, the cells composing heart muscle are

striated and nucleate, resembling skeletal muscles in being capable of rapid, powerful contractions, but unlike other muscles by reason of their regular automatic contraction and relaxation.

MUSCULAR CONTRACTIONS. That muscle contraction is stimulated by a nerve impulse in the living animal has long been proved, but this is as far as we can at present safely go, for in seeking a physico-chemical explanation of what actually happens within the cell itself we are treading upon dangerous ground. At the present time there does not appear to be an accepted theory that accounts completely and satisfactorily for muscle contraction.

Certain things, however, are definitely known. In the first place, muscles shorten when they contract. Under the microscope, the light and dark bands so readily seen in striated muscle appear to exchange places. In reality, the light bands have become dark and the dark ones light so that there has been no actual exchange of position but only a change in physical make-up. Chemically, muscular action is due to a series of complex chemical reactions which undergo a number of complicated changes, yielding in the end specific amounts of lactic acid. It is known that the shortening of the muscle fibers occurs *before* and *independently* of the formation of the acid and therefore it is difficult to believe that the two are unrelated. When muscular activity is prolonged, or when it is carried out under conditions implying a lessened supply of oxygen, there is an accumulation of so-called waste products, especially of lactic acid. According to Hill (1923) experiments on man caused an increase of from 29 to 104 mg. of lactic acid per 100 cc. of blood in the case of violent exercise carried on for one and a half minutes. This large increase in acid has been interpreted as meaning that the supply of oxygen to the contracting muscles was inadequate. Even with increased respiration and circulation, lactic acid accumulated in the muscles and was given off to the blood, thus creating an "oxygen debt" to the muscles. This phenomenon is associated with the condition of fatigue and has been studied in athletes, especially track men, where it was found that an accumulation of lactic acid hinders muscular relaxation. In races the intake of oxygen is of course determined by the efficiency of the lungs and heart. In long distance running the athlete reaches an equilibrium between his oxygen intake and lactic acid production. In short races he may breathe but once or not at all and so builds up a large oxygen debt. In such cases a state of exhaustion may be reached in a few seconds.

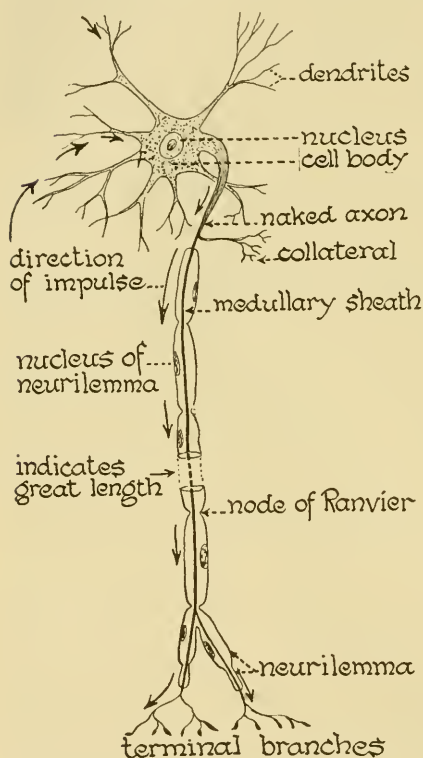
SECTION C. MECHANISMS OF SENSATION AND CO-ORDINATION

The Morphological Unit — The Neuron

In order to get at the secret of control of skeletal, muscular, and nervous systems, it is necessary to examine the various nervous devices found throughout the animal kingdom which have been developed as co-ordinators. All animals, except perhaps the protozoa, are built up of a number of essentially similar cell units. The complexity of the adjustment device is directly related to the way these units are

put together, as well as to the actual number of the units comprising the nervous system.

Since the fundamental unit of structure of the nervous system is the nerve cell (*neuron*), we will do well to examine it further. A typical neuron consists of a cell body and two kinds of out-growths, the many branched *dendrites* which receive impulses, and the elongated *axon*, that conducts messages away from the body of the cell, and terminates in the *end organs*. The "naked" axon is characteristic of the gray matter of the central nervous system. Around many of the axons is a thin, membranous protective covering, called the *neurilemma*, or *Schwann's sheath*. This is living tissue as shown by the nuclei scattered through it, and by the fact that it may be regenerated after injury. Neu-



A typical multipolar nerve cell.

rons of this latter type are found in most invertebrate nervous systems, in some of the prochordates, and in some of the peripheral nerves. In parts of the central nervous system of vertebrates the neurilemma is replaced by segments of white fatty substance, called

the *medullary sheath*, while other peripheral nerves possess both a medullary sheath and an outer *neurilemma*.

The manner in which neurons operate depends upon their "hook up." Contact without fusion (*synapse*) is made between the end organ of one neuron and the dendrite of another, resulting in continuity from the physiological point of view.

The Physiological Unit — Reflex Arc

The physiological unit of the nervous system is a *reflex arc*. Such arcs are made up of two or more neurons and a muscle or gland element. A *simple arc* consists of a receptor neuron, the dendrites of

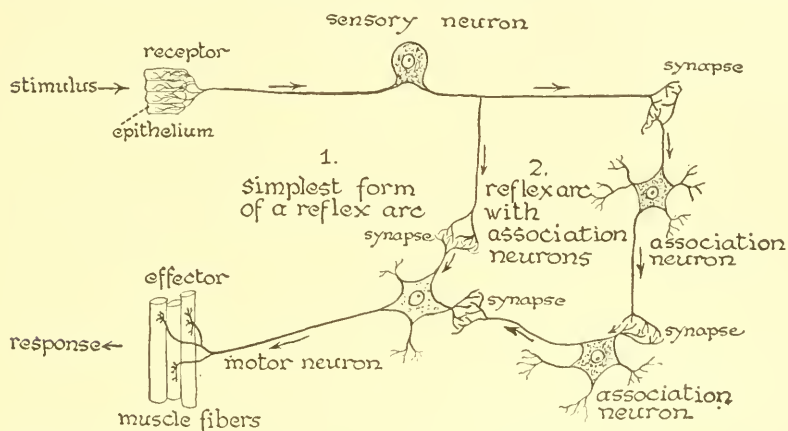


Diagram of reflex arcs. Explain why this is often called the "physiological unit of the nervous system."

which receive the stimulus and transmit it *via* the axon to the spinal cord where a synapse with the dendrites of an *effector cell* occurs. The impulse is then transmitted by means of the latter's axon to the *muscle* or *gland cell*. Reflex arcs generally require one or more *adjustor neurons* in the circuit between the receptor and effector cells. Such adjustor cells are usually located in the spinal cord or in the brain.

Even so brief a discussion of reflexes cannot be concluded without mention of the compound reflex arcs which are formed by a single receptor neuron and two or more effectors that may be widely separated in the body, or by two or more receptors and a single effector. Varying complexities of these latter types are made by the inter-

polarization of *adjustor* neurons. It is a moot question whether or not the simplest type of reflex arc, involving only two neurons, ever occurs in vertebrates. Most of the so-called "reflex actions" of man are usually not isolated from the rest of the nervous system.

In lower vertebrates, such reflexes as are concerned with locomotion, breathing, swallowing, and escape from danger are automatic spinal cord reflexes. When it comes to forms with complicated and highly developed nervous systems, such as man, many actions become automatic, relieving the brain ordinarily of any responsibility concerning them. In this category fall such phenomena as breathing, sneezing, and shivering. Certain actions, namely jerking of the knee, dodging a blow, closing the eyes to keep out foreign particles, are reflexes which may be controlled or inhibited by a conscious effort. Still more complex reflexes are called into action when playing a musical instrument, or in walking, talking, swimming, or driving a car.

Types of Nervous Systems

One of the fundamental characteristics of protoplasm is irritability. In simple types of animals, like *Ameba* or the sponges, where co-ordination between parts is not essential, no specialized nervous system is developed. With the aggregation of cells in higher forms there arises the necessity of correlating the interaction of component parts and consequently some sort of definite nervous system has been evolved. To be sure, such devices are quite unspecialized compared with the complicated nervous apparatus of a vertebrate, but nevertheless they appear to be reasonably effective.

Neuromotor Mechanisms

Ameba, although a very simple type of organism, gives evidence of being definitely affected by stimuli. This is shown by the passage of stimuli from one point on the surface to the general mass of the body, causing the animal to move away from the source of stimulation and resulting in the formation of pseudopodia on the opposite side. Experiments upon *Ameba* suggest that stimuli are transmitted in the clear outer layer of ectoplasm.

Probably the highest development of a co-ordinating system among the protozoa appears in some of the ciliates. We have already discussed movement in *Stylonychia* and in *Euplotes*. Considerable

experimental work has been performed, largely by Kofoed and his students at the University of California, upon co-ordination in the latter form. *Euplotes* is characterized by a group of anal cirri, while the anterior surface possesses an undulating membrane, near one end of which lies a co-ordinating center, or *motorium*. From this, fine protoplasmic threads emanate leading to various parts of the ciliate. Five of these strands lead to five anal cirri. Cutting these protoplasmic threads causes disruption of the rhythm of their movement, thus furnishing experimental evidence of the existence of a neuromotor apparatus in certain ciliates.

Co-ordination by a Network

In some of the most primitive metazoan forms, such as the sponges and the lower coelenterates, there is evidence of a very elementary and simple type of co-ordinating mechanism. A form like *Hydra*, which makes a variety of different movements, reacts to various stimuli since it feeds, contracts, expands, creeps, and occasionally turns cart-wheels. The mechanism which makes such acrobatics possible in *Hydra* has been described as a *nerve net*, and as such forms a part of the sensory-neuro-muscular mechanism, or as it is sometimes called, the *receptor-effector system*.

Co-ordination by a Nerve Ring

Only two of all the great phyla of animals, the coelenterates and the echinoderms, are apparently radially symmetrical. The nervous system of the first of these radially symmetrical groups has just been described and it can be seen how unspecialized are its co-ordinating devices. Turning to the echinoderms, as examples of the second radially symmetrical group, we find that in spite of the fact that embryos of these invertebrates are bilaterally symmetrical, the nervous system of the adults has developed along the lines of radial symmetry. This type of nervous system is composed of several parts, the relative development of which varies in the different classes, the starfish having numerous *nerve cells* lying among the ectodermal cells. Some of these nerve cells may connect with nerves from the fairly definite ridges of nerve tissue known as the *radial nerve cords* running the length of each arm and uniting to join a *nerve ring* that encircles the mouth. In addition there may be an *apical nervous system* that

innervates the dorsal muscles of the arms. As might be expected, the tube-feet in the starfishes (Asteroidea) are supplied with sensory organs. It is also interesting to note that at the tip of each arm of a starfish there occurs a light-perceiving organ.

Co-ordination by a Linear Nervous System

Once the flatworms are reached in the evolutionary series one finds the beginning of a linear type of nervous system. In the segmented worms, or annelids, the nervous system is composed of two main longitudinal, closely associated nerve trunks from which the several branches in each somite pass laterally. Each segment of the worm usually contains one, or, if the longitudinal cords are widely separated, two ganglia arranged in parallel lines. In such cases the ganglia are connected by a *transverse commissure*. This ladderlike type of nerve co-ordination reaches its peak in the arthropods, where well-developed ganglia occur in most somites. In nearly all types of the higher invertebrates there is in the head end a ganglionic mass of nervous tissue which has been dignified by the appellation of "a brain," whereas it should have been more properly known, because of its position, as a *supraesophageal ganglion*. All nerve cords of similar type are ventral in position and lie beneath the gut. In order to reach the supraesophageal ganglion, the nerve cord splits at the large *infra- or subesophageal ganglion*, and passes *around* the esophagus by means of the *circumesophageal connectives* or *loop*.

Reaching the arthropods, the primary change in the central nervous system is found to be a greater concentration of ganglia. In the larval forms of insects, there is little change from the linear nervous system of annelids. In adult insects, however, ganglia are concentrated, and even fused, in the regions of special organs. For instance, the "brain" and subesophageal ganglia are connected with the *ocelli*, antennae, and mouth parts, while thoracic ganglia are associated with the wings and other appendages. An autonomic (sympathetic) nervous system, which is believed to control the action of the heart, digestive system, and spiracle muscles, makes its debut in the arthropods.

Co-ordination by a Dorsal Tubular Nervous System

Among the vertebrates there is a highly developed dorsal, tubular, central nervous system with evidence, even in the lower forms, of

distinct cephalization. The nervous system serves to correlate movements and to give information of changes in the environment. Innumerable fibers extend from an elaborate central controlling device to all parts of the body. Such a nerve mechanism may be subdivided into several parts. For example, in man there is a *central nervous system*, a *peripheral nervous system*, and an *autonomic* or *sympathetic nervous system*.

Protective Devices for the Central Nervous System

As this centralized nervous system is the master which controls all voluntary acts and indirectly all parts of the body, it is of primary importance to protect so delicate a mechanism from injury. Since the situation is essentially the same among the different members of the large group of vertebrates, attention will be primarily directed to the system as it is found in mammals, and more particularly in man.

The skull and the vertebral column serve as the "first line of defense" for the all-important brain and spinal cord against possible attack or injury. However, "secondary defenses" must also be present. The inner surface of the skull and the vertebral column, therefore, is lined with a tough membrane of fibrous connective tissue, called the *dura mater*. Inside the *dura mater* the central nervous system itself is also covered with a thin, closely investing membrane, the *pia mater*, while between it and the *dura mater* lies the delicate serous membrane known as the *arachnoid*. These three membranes furnish additional protection to the central nervous system, but they would be relatively ineffectual without the buffering effect of the *cerebrospinal fluid* which fills the spaces between the *arachnoid* and *pia mater*. Thus the vertebrate nervous system is insulated, cushioned, or, to put it more graphically, furnished with "shock absorbers," that enable man and other vertebrates to withstand severe shocks without injury.

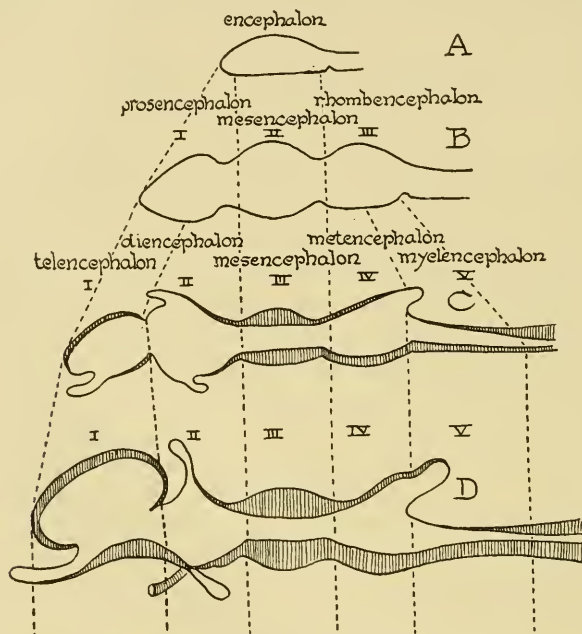
Anatomy and Development of the Brain

The Early Development of the Central Nervous System

Amphioxus gives but slight evidence of an enlargement of the cephalic end of the dorsal tubular nerve cord, but in the bony fishes there are already five main divisions in the adult brain. These same divisions are to be found in every one of the different vertebrate classes, and all representative vertebrate brains have a similar embry-

ological history. In other words, these structures are both homologous and in a general way analogous.

Some of the more important changes in the growth and expansion of the nerve cord are as follows. Early in its embryonic development, before the five regions of the brain are developed, the anterior portion of the growing nerve cord becomes differentiated into three enlargements, designated, beginning anteriorly, as the fore- (*prosencephalon*), mid- (*mesencephalon*), and hind- (*rhombencephalon*) brains.



Development of the vertebrate brain from a simple encephalon.

Most of the subsequent development takes place in the fore- and hind-brains (page 347). As growth continues, the anterior part of the fore-brain divides, grows out into two pouchlike lateral lobes, called the cerebral hemispheres (*telencephalon*), or collectively the *cerebrum*. The posterior portion of the primitive fore-brain is now designated as the 'twist-brain' (*diencephalon*). The mid-brain (*mesencephalon*) meanwhile remains undivided, while the hind-brain becomes separated into an anterior dorsal outgrowth, called the cerebellum (*metencephalon*), and a posterior medulla oblongata (*myelencephalon*), which is continuous with the cord.

Before going further with a consideration and discussion of the human nervous system, a comparison of brains of different vertebrates should be made for the sake of clearness.

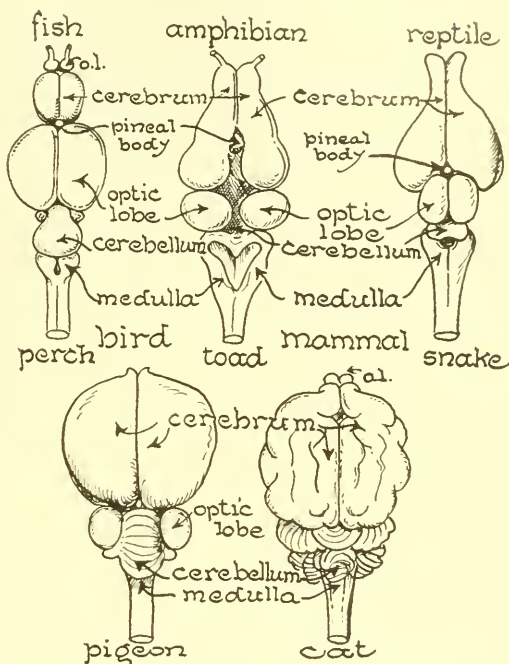
Remembering that the brain of a fish is not folded upon itself as is the brain of a mammal, it is easy to see that the introduction of *flexures* tends towards greater compactness. Another outstanding development is the increase in size of some of the regions of the brain. In lower forms, the dominating portions of the brain from the standpoint of mass are the optic lobes of the mid-brain and the medulla oblongata, and, as might be inferred, both the cerebrum and cerebellum are quite small. In the higher mammals,

however, these organs become two of the most important centers in the brain, increase in the size of the cerebrum being in direct proportion to the intelligence of the animal.

An examination of a few of the more important landmarks of the divisions of the brain in order to secure a general idea of the functioning of each of these parts will furnish a background for the discussion of the "Display of energy."

The Parts of the Vertebrate Brain

THE CEREBRUM OR TELENCEPHALON. As the adult condition is approached, certain other characteristic structures appear. From the anterior portion of the cerebrum grow the paired *olfactory lobes*. In lower vertebrates these may extend into expanded *olfactory bulbs*,



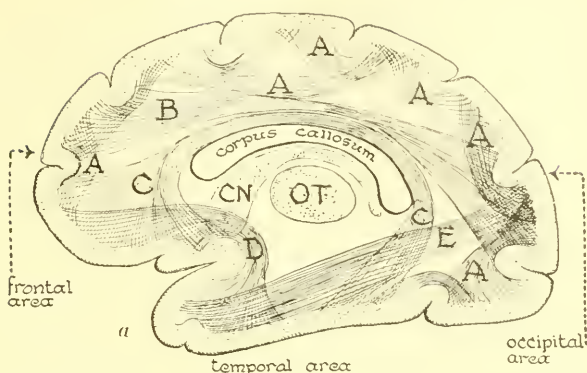
Representative vertebrate brains. *o.l.*, olfactory lobes. What regions increase noticeably in mass from fish to mammals? How are these changes correlated with the shift from water to land? (After Guyer.)

from which the olfactory nerves pass directly to the nostrils, thus receiving stimuli which are interpreted in the brain as odors.

The cerebral hemispheres contain cavities known as the *first* and *second ventricles*, which are continuous posteriorly with the *third ventricle*, found in the 'twixt-brain or diencephalon. Dorsally and laterally the cerebral walls are known as the *pallium*, that furnishes a foundation on which the outer layer, or *cortex* is developed. In the higher vertebrates a connecting bridge of white fibers, called the *corpus callosum*, unites the two cerebral hemispheres. The higher the mammal is in the scale of life the more convoluted the cortical surfaces of the hemispheres become, and the more the cerebrum weighs in proportion to the rest of the organ. A rabbit's cerebrum composes slightly more than half of the mass of the entire brain, while in man it exceeds four fifths of the total weight.

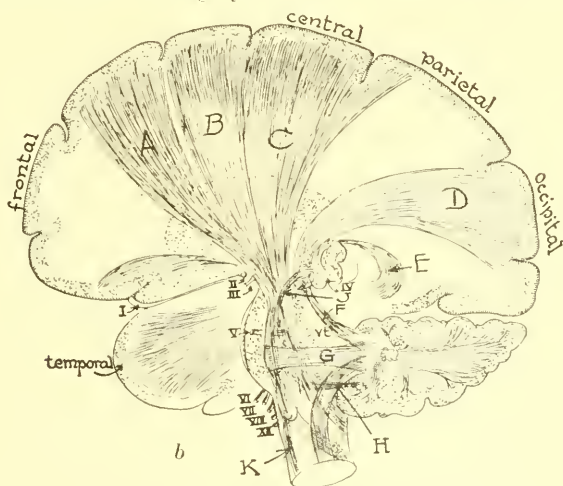
The superficial cortical layer of the cerebrum forms a mass made up of numberless nerve cells interwoven into an intercommunicating network. The axons of some of these neurons pass over the bridge of the corpus callosum from one side to the other while other axons extend downward in great bands as far as the cerebellum and to other more posterior centers. It has been demonstrated that this portion of the brain is the seat of consciousness and the controlling center of all our higher mental life. As the cerebral functions increase, the instinctive reflexes retire further into the background. Herein lies the chief difference between the so-called lower animals and the higher ones. The former are chiefly at the mercy of their hereditary limitations and their environment, while the latter have risen sufficiently above their environmental conditions to begin at least to become "the captains of their souls." A series of experimental operations on a dog, in which the entire cerebrum was finally removed, illustrates the importance of this part of the brain to the higher animals. The dog in question apparently became an idiot, unable to associate experiences or to learn. It had no ability to differentiate between solid objects in its path and patches of sunlight on the floor, which could in no way hinder its progress.

THE 'TWIXT-BRAIN OR DIENCEPHALON. This region is comparatively inconspicuous, but very essential to the biologist, since the ventral floor of the 'twixt-brain gives rise to an outgrowth called the *infundibulum*, which fuses with a dorsal outgrowth from the roof of the mouth to form the *pituitary gland* (*hypophysis*), the "generalissimo" of the ductless glands. Possibly because of its importance it has



Two figures illustrating the intercommunicating pathways of nerve fibers in the human brain.

a. Various association fibers of the human brain. *A*, between adjacent areas; *B*, between frontal and occipital areas; *C*, *D*, between frontal and temporal areas; *E*, between occipital and temporal areas. Note the corpus callosum which contains large groups of association fibers and connects the cortex of the right cerebral hemisphere with that of the left. The caudate nucleus, *CN*, and the thalamus, *OT*, both contain gray matter.



b. Scheme of projection fibers connecting the cerebrum and other parts of the brain. *A*, tracts from frontal lobe to the pons varolii and thence to the cerebellum via *G*; *B*, motor (pyramidal) tracts; *C*, sensory tracts; *D* and *E*, the visual and auditory tracts, respectively; *F*, fibers connecting the cerebrum and cerebellum; *G*, fibers connecting the cerebellum and the brain stem; *H*, fibers between the cerebellum and the cord; *J*, fibers connecting the auditory nucleus and the brain stem; *K*, crossing over of motor (pyramidal) tracts in the brain stem; *V*, fourth ventricle. The numbers refer to the cranial nerves. (Both modified from Starr.)

become exceptionally well protected. In all mammals this little gland is lodged in a protective median depression in the sphenoid bone of the skull called the "Turk's saddle," or *sella turcica*. The 'twixt-brain also gives rise laterally to outgrowths of the lateral wall which form the *optic stalks* that are essential to the development of the eyes. In this region of the brain several problematical structures, of particular interest to the comparative anatomist, such as the *pineal eye*, have their origin. The cavity of the 'twixt-brain is called the *third ventricle*.

THE MID-BRAIN OR MESENCEPHALON. This portion of the brain has kept many of its primitive embryonic characters, its gray matter being still found largely in ganglionic masses. Anatomically, it is a small region, the lumen of which, communicating anteriorly with the third ventricle, is called the *aqueduct*. In lower forms like the fishes and amphibia, the roof of this cavity is expanded dorsally into two rounded protuberances, the *optic lobes*, or *corpora bigemina*. The optic lobes of reptiles, birds, and mammals become further divided into two pairs of centers known as the *corpora quadrigemina*, from which are sent out bands of fibers, the anterior pair being connected with the eyes, and the posterior pair with the ears. In forms below the mammals the mid-brain functions as a co-ordinating center for impulses entering through the eye, ear, and certain nerves of the body. In the mammals much of this co-ordinating function has been taken over by the cerebrum. Upon the latero-ventral surface of the mid-brain may be seen a band of fibers, the *crura cerebri*, forming a highway of communication between the cerebrum and the posterior parts of the central nervous system. Two motor cranial nerves, the *oculomotor* (III) and the *trochlear* (IV), which supply muscles of the eye, arise here.

THE CEREBELLUM OR METENCEPHALON. While the surface of the cerebellum is not convoluted in the same manner as the cerebrum, nevertheless its surface of gray matter is increased by being thrown into numerous furrows. It is composed of two hemispheres connected by a bridge, the *vermis*, and has consequently been likened to a butterfly with the bridge forming the body. The cerebellum lies just posterior to the cerebrum and dorsal to the mid-brain. When cut in sagittal section it is seen to be composed of radiating folds, arranged in an outer layer of gray matter and an inner core of white matter. Taken as a whole the white matter somewhat resembles a tree and so has been called the *arbor vitae*, or "tree of life."

Ventrally, a swollen band of fibers, called the *pons varolii*, is

plainly evident because of the transverse direction of its fiber, crossing from one side of the cerebellum to the other. Nerve fibers arising in the frontal, parietal, and occipital lobes of the cerebrum reach the cerebellar hemispheres by way of the *anterior peduncles* in front of the pons, the latter bearing some resemblance to a pair of legs supporting the body of the cerebellum. There is a second pair of lateral "legs" behind the pons, the *posterior peduncles*, which contain communicating fibers between the cerebellar lobes and the posterior regions of the central nervous system. Thus, a highway of communication with the cerebrum is at hand and herein lies a partial explanation of man's ability to perform purposive acts as the result of the various visual, auditory, and other impressions of the senses. Experimental evidence indicates that this portion of the brain is primarily a seat of muscular co-ordination.

If the cerebellum of a dog is removed, the animal is unable to co-ordinate its movements at first. Later it learns to walk, but the gait is always slow and staggering. In a similar condition, a pigeon is unable to fly, but like the dog, may eventually learn to walk again, although resembling the proverbial inebriate in its gait. It has often been claimed that man would make a better recovery after removal of the cerebellum than either the dog or bird since his more highly developed cerebrum would compensate the loss. In any case, from these experiments the importance of the cerebellar region of the brain in our everyday activities is better understood.

THE MEDULLA OBLONGATA OR MYELENCEPHALON. The brain at this point is anatomically little more than an expanded region of the spinal column, but it is the sole means of communication between the cerebrum and the body. Its dorsal surface is partially covered by the posterior peduncles, and there is also a very thin non-nervous roof, the *metatela*, which covers the *fourth ventricle*, or the large cavity of the brain of this region. Ventrally, two raised convex columns of fibers may be seen, known as the *pyramids*.

In the gray matter of the medulla, the controlling centers for many of the essential functions of life are found, for example, the reflexes concerned with the vasomotor and respiratory functions. Numerous other centers that control swallowing, coughing, sucking, sneezing, salivary secretions, gastric secretions, heart inhibition, and other activities connected with the living body are located in the medulla.

All of the cranial nerves, except the first four pairs, arise from this region. It is here, too, that the *pyramidal tracts* of transmitting fibers

cross from one side of the brain to the other, like the letter "X," so that the control of the left side of the body is located in the centers of the right side of the brain and vice versa.

The Cranial Nerves

There are typically ten pairs of cranial nerves in the lower vertebrates and twelve in mammals, arising from different parts of the brain. Of these, four pairs are of particular interest. Three pairs (I, II, and VIII) are concerned with the innervation of the organs of special sense, while the fourth (X) is that great wanderer, the *vagus*.

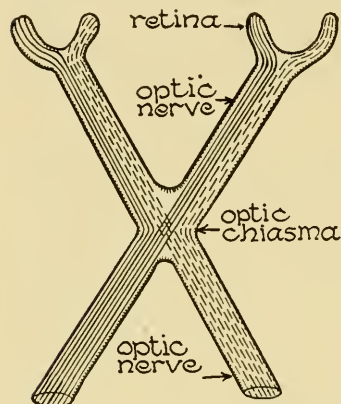


Diagram showing the optic chiasma in man. Note that the crossing is not complete, a condition probably related to the binocular method of vision.

The first, or *olfactory nerve* (I) receives stimuli from the nose and conveys them to the brain. The second, or *optic nerve* (II) emerges from the lateral floor of the diencephalon, its fibers more or less completely crossing in the *optic chiasma*, that lies just anterior to the infundibular outgrowth of the pituitary body already mentioned. This nerve transfers the impulses which are interpreted in the brain as sight. The third pair of cranial nerves associated with a special sense is known as the *auditory nerve* (VIII), and has the dual function of hearing and equilibration.

The remainder of the cranial nerves will be omitted from further discussion except the *vagus* (X), the ramifications of which are more extensive than those of any of the other cranial nerves. The *vagus* is a mixture of motor and sensory elements, the former supplying muscles of the pharyngeal and laryngeal region, most of the digestive tract and the liver, pancreas, and spleen, the kidneys as well as the heart, and certain blood vessels. The sensory fibers are distributed to the mucous membranes of the larynx, trachea, lungs, esophagus, stomach, intestines, and gall bladder. Inhibitory fibers also reach the heart and, in addition, this versatile nerve supplies the gastric and pancreatic glands with secretory fibers. Much of phylogenetic interest may be gleaned from a careful comparative study of the distribution of this and other cranial nerves from fish to man.

The Spinal Cord

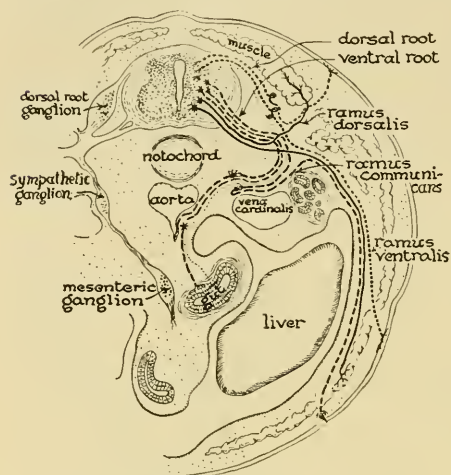
The medulla oblongata is continued almost imperceptibly over into the spinal cord, which extends in adult man from the *foramen magnum* of the skull posteriorly through the vertebral column for seventeen to eighteen inches. The spinal cord is, roughly speaking, the size of the little finger, or about 0.4 of an inch in diameter. Two enlargements occur in it, one in the region of the shoulder-blades, and the other below the small of the back, respectively known as the *cervical* and *lumbar* enlargements.

The internal structure of the cord is quite characteristic. In cross section, the central gray matter somewhat resembles the letter "H," the position of the gray and white matter being apparently reversed from their position in the brain. As a matter of fact, in both cord and brain the gray matter is disposed inside close around the cavity that extends throughout the whole central nervous system. Outside this central gray matter are the transmission fibers which appear white. In the cerebellum and cerebrum of the brain there is superimposed an outer layer of gray matter that constitutes the centers of adjustment. This secondary gray layer is so pronounced in the brain that it gives rise to the popular impression of a reversal in the arrangement of white and gray matter between the cord and brain. The gray matter is composed of a ventral, or *anterior*, and a dorsal, or *posterior*, *column*, divided into these two parts by the transverse bar of the "H." The white matter may also be subdivided into three parts on either side, a *ventral*, *lateral*, and *dorsal funiculus*.

The Spinal Nerves

The nerves in this group, like the cranials, are paired, there being 31 pairs in man. Each nerve, moreover, is "mixed," that is, it is composed of a *dorsal* or *sensory root* containing receptor neurons, carrying messages toward the brain, and a *ventral* or *motor root* bearing effector neurons, which carry messages away from the brain to muscles and glands. It will be noted that some of the cranial nerves, unlike the spinal nerves, have lost this original ability to transmit messages both ways and have been reduced to one-way traffic, for example, the three pairs of eye-muscle nerves (III, IV, and VI) handle only outgoing impulses, while the auditory nerve (VIII) can only transmit stimuli inward toward the brain. From the point in a mixed nerve where the incoming and the outgoing roots fuse are typically given off the

following branches: (1) a *dorsal branch*; (2) a more prominent *ventral branch*, which supplies the skin and body musculature; (3) a *communicating branch*, going to



Components of a spinal nerve. Somatic motor fibers are indicated by solid lines; visceral motor by long dashes; somatic sensory in short dashes; visceral sensory by dotted lines.

also be thought of as an auxiliary, or perhaps more properly a relay apparatus to supplement the work of the central nervous system.

Anatomically the system consists of two "longitudinally connected" chains of ganglia lying on either side and just ventral to the cerebrospinal cord together with various ganglia scattered throughout the viscera and groups of connecting nerves extending to the central nervous system. This system is divisible into two parts. The first is called the *thoracolumbar* part, and consists of the double chain of ganglia mentioned above together with the connections through the spinal nerves. It reaches the blood vessels, heart, digestive tract, and many other parts of the body. The second, or *parasympathetic part*, is characterized by having three centers, two cranial centers, one in the mid-brain, one in the medulla region, and a posterior center in the sacral region.

Masses of nervous tissue are scattered as ganglia which are located in various organs, such as the walls of the digestive tract, where they are known as the *solar*, *cardiac*, or *aortic plexuses*. These serve as relay centers for impulses coming from the main trunk line of the autonomic

system and thence to the viscera; and (4) a small *meningeal branch*, going back to the protective layers of the cord. Thus the nerves emanating from this point of fusion are mixed in character while their roots are not.

The Autonomic Nervous System

The term *autonomic nervous system* embraces all nerves and ganglia located outside of the spinal cord, which regulate the activities of smooth, or involuntary, muscle and various glands. It should

system, and since each of these centers usually presents a fanlike arrangement of efferent fibers, they serve to increase the number of available pathways.

The autonomic system is full of contradictions, for there appears to be an antagonistic action on the part of the thoracolumbar to

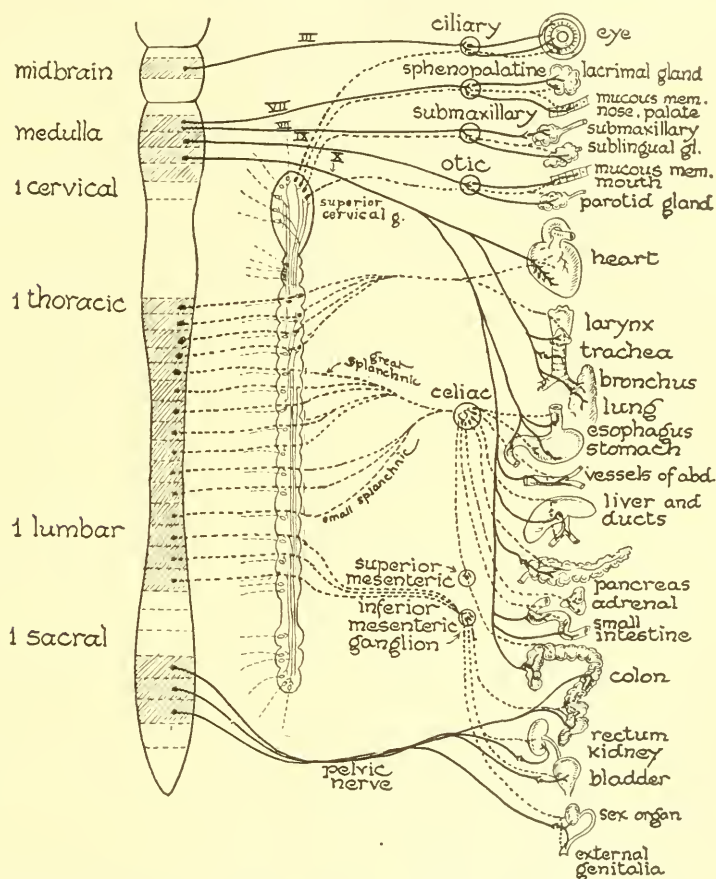


Diagram of the autonomic nervous system. The parasympathetic part appears in solid lines and the thoracolumbar part in dotted lines.

impulses from the cranial or sacral parts of the parasympathetic system. Thus the cranial part slows the heart while the thoracolumbar accelerates it. This has often been spoken of as "reciprocal innervation," a principle which plays a very important rôle in the proper functioning of various organs.

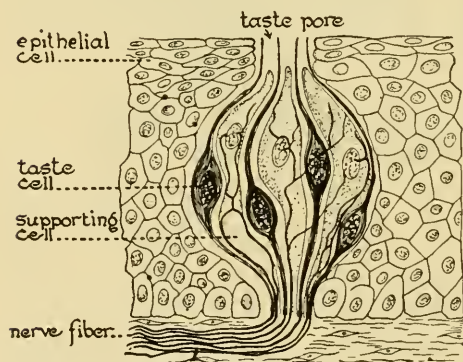
The origin of the autonomic system has been the subject of considerable speculation. Some investigators believe that it has been secondarily derived from the central nervous system probably by the migration of cells. Others support the idea that it is in reality a primitive ancestral apparatus which is more or less homologous with the nervous system of invertebrates. According to this theory the autonomic system has become secondarily subservient to the voluntary nervous system of the vertebrates.

The Sense Organs — Receptor Devices

The mechanism and functioning of many of the different parts of the vertebrate nervous system have been considered in some detail for the purpose of showing how the voluntary system controls actions, and also how the involuntary system has taken over the burden of running the body. It now remains to trace the various devices that have been developed to help an animal keep in touch with its environment, in other words the sensory receptors, which range from specialized to rather generalized structures and are usually classified as organs of taste, smell, sight, hearing, and the tactile sense.

Taste

In the lower vertebrates the sense of taste is quite widely distributed. For example, in some of the fishes sensory cells of chemical



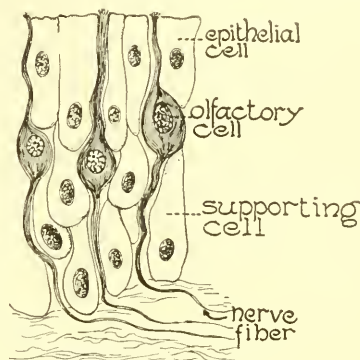
A taste bud. Explain how it functions.

reception are scattered somewhat widely over the body surface. In higher vertebrates such organs are mostly restricted to the surface of the tongue and are known as *taste buds*. Most people labor under the delusion that they can distinguish between a great variety of flavors. Actually, however, buds are sensitive to only four kinds of stimuli, sweet, sour, bitter, and

salty. The confusion results from the inclusion of interpretations of sensations received by the olfactory senses.

Smell

This is one of the more important organs of special sense. Even aquatic forms have been shown to possess a fairly keen sense of smell. In land forms, the nasal chamber becomes supplied with sensory olfactory cells that are quite primitive, or undifferentiated. The insects, which in some cases have a keen sense of smell, have the olfactory organs located on the antennae. Loeb performed an experiment that clearly demonstrated the acuteness of this sense in a butterfly, by suspending a female butterfly in a box and then opening the window. In less than half an hour a male butterfly of the same species was nearby. It soon reached the window, flew into the room, and perched on the box.



Two other males also came during the afternoon. Their sense of smell no doubt was responsible for their discovery of the female. Man, whose sense of smell is by no means as keen as that of some other animals, can, nevertheless, detect, for example, one part in a million of iodoform.

Simple Light Receptors

The reaction of animals to light is one of the most characteristic responses found in the animal kingdom. In the simplest organisms it has been demonstrated that this reaction may be classified as a positive or negative attraction to light. The ability to react to light indicates the presence of cells or tissues in the animal which are photosensitive. Since, in lower forms, the response to light may be detected by the manner in which the animal reacts in the presence or absence of light, or in avoiding illuminated areas, it appears probable that there is a more or less direct connection between the photoreceptor cells and the muscles. The responses to light of such animals as the protozoa, hydroids, and earthworms apparently fall into this category, and has led to their being designated as positively or negatively phototropic. Much interesting experimental work has been done along these lines.

Compound Eyes

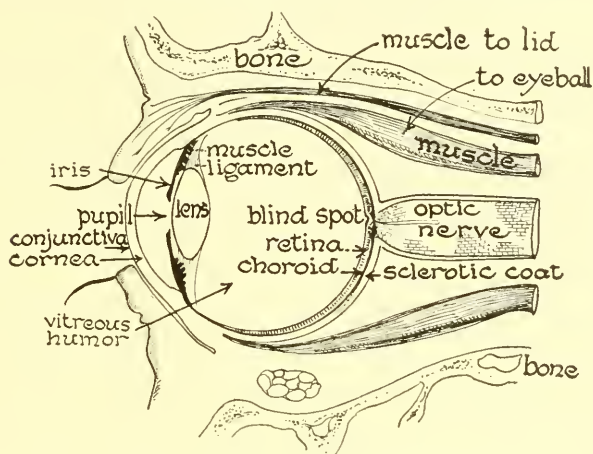
The intergradation from the type of photosensitive cells mentioned above, to a primitive eye, or eye spot, is a gradual one. One of the first steps in the production of a simple eye spot appears to be the concentration at a given point of a number of light-sensitive cells connected with nerves. From such simple beginnings two types of eyes have been evolved in the animal kingdom, the *compound eye* of the insects and crustacea, and the *camera eye* of certain molluscs and the vertebrates. The compound eye is composed of a varying number of complete individual eyes called *ommatidia*. Each ommatidium is directly connected with the brain and produces a separate image that, joined to others, gives a unified picture. It has been ascertained by counting the exposed surfaces, or *facets*, of the ommatidia that there may be present any number from a few dozen up to several thousand. Some ants have about fifty, while the swallowtail butterfly has seventeen thousand, and dragonflies still more in each eye. The walls of each ommatidium are surrounded with pigment cells that absorb all tangential rays, consequently only those rays which penetrate straight in through the facet reach the sensory areas located in the *retinular*, or photoreceptive, *cells*. On account of this restricted intake, each ommatidium receives for interpretation only a small portion of the rays entering through the cornea. It is believed that there is no marked overlapping of images since each image is recorded in a different spot, the end result being a series of small images one next the other, which act to produce the completed picture, called an *erect mosaic* (see figure, page 206).

Camera Eyes

The camera type of eye in invertebrates reaches its peak in the molluscan squid and, among the vertebrates, in the human eye. These two types offer a good illustration of analogous structures. A study of the development of these two types of eyes shows that the position of certain elongated cells of the retina, called the *rods* and *cones*, are reversed in the two forms, and consequently while their function is in general the same, or analogous, their type of structure, or homology, is different. The vertebrate eye is almost spherical, and fits into a funnel-shaped socket of bone, called the *orbit*, while the stalklike, optic nerve connects the eye directly with the brain. Free movement is made possible by means of six small muscles which

are attached to the outer coat of the eyeball and to the bony wall around the eye.

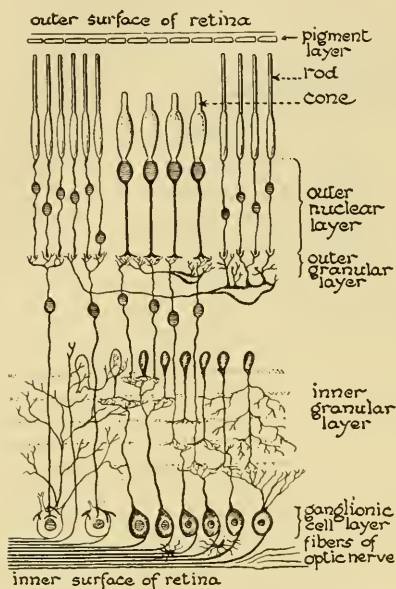
The wall of the eyeball is made up of three coats. The outer tough white coat of connective tissue is called the *sclerotic coat*. In front, where the eye bulges out a little, the outer coat becomes transparent, forming the *cornea*. A second coat, the *choroid*, is supplied with blood



Sagittal section of a mammalian eye.

vessels and cells containing considerable quantities of black pigment. The *iris*, which shows through the cornea as the colored part of the eye, is a part of this coat. In the center of the iris there is a small circular hole, the *pupil*. The iris is under the control of involuntary muscles, and may be adjusted to varying amounts of light, the hole becoming larger in dim light and smaller in bright light. The inmost layer or coat of the eye, called the *retina*, is double, consisting of an outer pigmented and an inner sensory part. This is perhaps the most delicate layer in the entire body. Despite the fact that the retina is less than $\frac{1}{80}$ of an inch in thickness, it is composed of several layers of cells. The optic nerve, made up of a chain of relaying neurons, enters the eye from behind and spreads out over the surface of the retina. At its point of entry a cross section of the optic nerve shows that the nerve consists only of axons of neurons, and consequently this "blind spot" is not sensitive to light. The ultimate photoreceptors are numerous elongated cells, called *rods* and *cones*. The function of the rods is a highly specialized sensitivity to light, and of the cones the perception of color. In the optical center of the

posterior part of the retina lies a region known as the *yellow spot*, or *macula lutea*. The central pitlike portion of the macula lutea, where cones predominate, almost to the exclusion of rods, is designated as the *fovea centralis*, since it is here that the keenest vision occurs. The retina is thinner at this point and the black pigment of the outer layer shows through from behind, making it dark purple in color, due to a layer of cells next to the choroid coat. The retina acts as the



Detail of retina showing rods and cones.

two chambers that communicate through the pupil, filled with a watery fluid, the *aqueous humor*, while behind it is the main cavity of the eye, filled with a transparent, almost jellylike, *vitreous humor*. The lens lies directly behind the iris and is attached to the choroid coat by means of delicate ligaments and by pressure of the two liquid media.

In order to function properly, the surface of the eye must be kept moist, and various glands are located in the cavernous orbit of the eye and along the edges of the eyelids which serve this purpose. The best known are the tear or *lacrimal glands* with their associated ducts that open into the nasal chamber. These glands increase their normal production of moisture to form visible tears when the surface of the eye is irritated by foreign particles or when the emotions gain control.

sensitized plate in a camera, for on it are received the impressions of light and shade and color which are transformed and sent to the brain resulting in sensations of sight. Like the camera, the eye has a *lens* formed of transparent elastic material, a circumstance permitting a change of its form and, in consequence, a change of focus upon the retina. By means of this change in form, or *accommodation*, both near and distant objects may be seen. In fishes, unlike mammals, accommodation is accomplished by shifting the position of the lens, as in a camera, rather than by changing its shape. In front of the lens is a small cavity, divided by the iris into

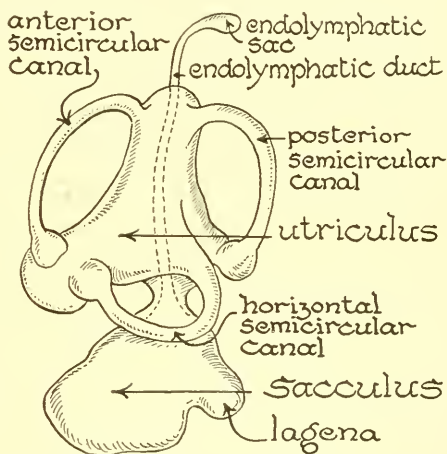
Ears

The structures making up the complicated mechanism of hearing primarily serve two purposes, namely *equilibration* and *hearing*. Of these functions the first is undoubtedly the more primitive.

Most invertebrates, whether jellyfish, molluses, or crayfish, maintain their equilibrium by some sort of *otocyst*. Roughly described, this consists of a sac lined throughout or in part by cell-receptors and containing concretions called *otoliths*. As the animal changes its position the otolith shifts due to the forces of gravity and thus stimulates by contact the different receptor nerve cells, which transmit the impulse of pressure to the brain, where it is interpreted so as to enable the animal to right itself.

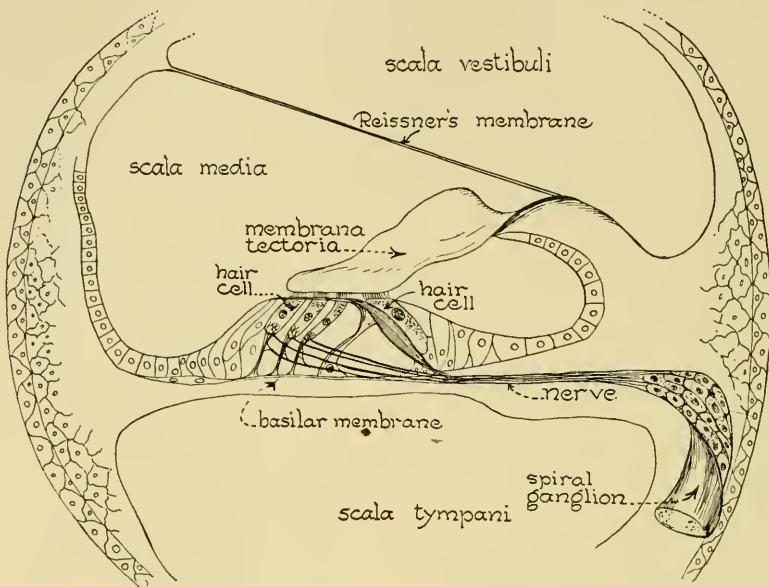
The equilibratory mechanism of vertebrates functions principally through stimuli received from nerve cells located in the *ampullae* or swollen ends of three *semicircular canals*, occupying roughly the three planes of space. The animal is enabled to adjust its position with reference to the stimuli received through the influence of gravity. In such cases the fluid within the semicircular system stimulates differentially the nerve endings in the ampullae. Stimuli reach the nerve-receptors in the same manner as they do in the lower forms, being carried by branches of the auditory nerve (VIII) in the brain. The entire structure is protected by a surrounding mass of cartilage which in higher forms becomes ossified.

As to the function of hearing, it is possible that in the case of fishes vibrations are transmitted by the water through the skull to the sensory inner ear. However, when air is substituted for water as the chief environment some other more sensitive device must be



The inner ear of a fish showing the essential features of this balancing organ. Where are the ampullae? These, together with areas in the *utricle* and *sacculus*, contain patches of sensory cells connected with branches of the auditory nerve. How are such areas stimulated? The lagena produces the cochlea.

developed. In the land vertebrates amplifying devices are developed in the form of a vibrating *ear drum* or *tympanic membrane* beneath the skin, and a chain of *middle ear bones* that transmit the vibrations to the inner ear where the sensitive receptor-cells are located. Thus



A cross section of the coiled cochlea which contains the organ of Corti in which the sensitive hair cells are located. The scala media is filled with fluid endolymph which is separated from the fluid perilymph of the scala vestibuli by Reissner's membrane. Vibrations of the ear drum are transmitted through the middle ear bones which cause the vibration of a membrane at one end of the scala vestibuli, thus disturbing the perilymph in the scala vestibuli. How are the hair cells stimulated?

there is gradually developed an elaborate mechanism by which vibrations are transmitted and amplified through the ear drum and the three bones of the middle ear to the spirally coiled portion of the inner ear, or *cochlea*, where the receptor-cells are located. These essential cells receive stimuli which are carried by branches of the auditory nerve to the brain for interpretation.

Cutaneous Sense Organs

There remains for consideration that diverse group of sense organs located in the integument. In fishes, the tactile sense consists principally of *pressure receptors*, which are usually concentrated along the

lateral line. The entire surface of the body of vertebrates in general is practically covered with receptors capable of interpreting touch or pressure, temperature, and pain.

These integumentary receptors, of which there are many modifications, are not located with uniform density over the body surface. It has been estimated that there are between 3,000,000 and 4,000,000 pain, 500,000 pressure, 150,000 cold, and 16,000 warm receptors located in the human skin.

An understanding of the sensations and impulses which are received from the organs of special sense is the primary means of keeping ourselves informed about changes taking place in our immediate surroundings. From these sensations and impulses are built up definite reactions as well as certain convictions or attitudes which enable us to secure the maximum or minimum out of life.

SUGGESTED READINGS

Clendenning, L., *The Human Body*, Alfred A. Knopf, Inc., 1930. Pp. 53-70, 223-250.

More popular reading.

Howell, W. H., *A Textbook of Physiology*, 12th ed., W. B. Saunders Co. 1933. Chs. I-V.

A thorough technical account of the physiology of muscle and nerve.

Rogers, C. G., *Textbook of Comparative Physiology*, McGraw-Hill Book Co., 1927. Chs. XXVI and XXVIII.

Advanced account from the comparative viewpoint.

Wells, H. G., Huxley, J. S., Wells, C. P., *Science of Life*, Doubleday, Doran & Co., 1931. Pp. 32-38, 523-524, 697-698, 1200-1226.

Popular account with emphasis on man.

THE DISPLAY OF ENERGY

PREVIEW. Why living things are responsive · Various kinds of stimuli · Tropisms · Nature of responses · Mechanism of response in plants · Mechanisms of response in animals · Tropisms, reflexes, and native behaviors · Native behaviors may be modified · Habit formation · Conditioned behaviors · Are behaviors adaptive responses? · When are animals conscious? · Emotional responses · What is intelligence? · Intelligence of apes · Intelligence of man · The measurement of intelligence · Suggested readings.

PREVIEW

The display of energy is characteristic of all living things. We may predict quite accurately what forms energy will take in very simple plants and animals, since they react variously but consistently to factors of the environment, such as light, temperature, and moisture, by making definite turning movements, growth movements, or by other behavior. These expressions of behavior are called *tropisms*.

When it comes to answering the question, "Why do we behave like human beings?" we are faced with a much more difficult problem, for the more complex the organism, the more complicated are its behavior patterns.

Comparing the behavior of plants with that of animals and using the same stimuli in each case, we find in general that, correlated with the lack of muscles and a nervous system, in plants responses to stimuli are slow and usually expressed as growth movements. In animals which, except in the lowest forms, have both muscles and a nervous apparatus, the reaction to a given stimulus is a response in the form of some sort of motion such as swimming, flying, crawling, walking, or running.

Two very definite theories of animal behavior are held. One theory recognizes animals as living machines, giving definite and unchangeable responses to certain stimuli. In such a mechanistic view of life the organism is considered in terms of groups of cells and tissues, or of the elements of which it is composed. When the machine is very complex its actions are less predictable because the same stimulus may cause a different reaction to a different part of the machine. Light, for example, would evoke a response only from

photoreceptive organs, while differences in temperature might affect many different groups of tissues or organs in different ways

Another view, quite opposite to this, is the *organismal theory*. Here the unity of the organism as an interacting whole is stressed. It is considered as an individual and not as a collection of cells and tissues. The study of embryology bears out this idea, for in the development of the egg certain regions of protoplasm, instead of certain cells, develop into the future embryo. The egg at an early stage shows polarity, a right and left side as well as an anterior and posterior end of the future organism, some time before it divides into cells. Professor Child of the University of Chicago has developed and tested a theory of the unity of the organism which he calls the *axial gradient theory* that helps in understanding the complex response patterns observed in the higher forms of life. He considers an animal as having definite axes of polarity, or symmetry, the anterior end containing the most sensitive receiving structures. Since the brain is the most active protoplasmic substance its metabolic rate is higher than that of the rest of the organism, while its activity controls other parts of the organism.

This concept of the organism is an aid to a better understanding of the complicated reactions and responses that are found in higher animals. It is difficult to explain the complex response patterns of vertebrates unless they are considered to be organized masses of protoplasm which respond as *units* to the total pattern of stimuli rather than to individual stimuli. Living animals, at least those high in the scale of life, respond to total situations rather than to isolated stimuli. Such a point of view is taken by the "Gestalt" group of psychologists, who use the term *insight* to describe an organized response at the conscious behavior level. Such a response can be shown to be directed toward a goal, the complex movements being organized in relation to that goal, the result of which is that the animal is able to solve its life problems. According to this theory, a child who is learning to walk does not make random "trial and error" movements. The uncertainty of its first steps is due to a lack of maturity of the muscles and of the nervous system, and not to the lack of a goal. This can be seen in a comparison of two children of the same age, one of whom is allowed to walk early, the other who has been kept off its feet for fear of having the legs bowed. The latter will walk almost at once when allowed to try the new "stunt." When maturity of muscles and nerves is attained it becomes possible for a total behavior pattern to

appear and walking takes place. The second child has both conditions present.

This explanation of the *display of energy* helps us to understand the mental life of higher animals, especially with reference to a directed urge toward definite goals of behavior. In the pages that follow an attempt will be made to show how conscious life has developed. No set theories or beliefs will be imposed on the reader, but a brief presentation of the facts will be given as we see them. The student can then do his own thinking.

Why Living Things Are Responsive

Life has been likened by many writers to a flowing river which continually moves in one direction. Meeting obstacles, it is diverted from its course, moving rapidly over steep declivities and meandering slowly in level valleys. We do not think of a river in terms of water alone, but also in terms of the rocks in its bed, of its banks of gravel or soil, even of the forests in which it takes its source, and of the wharves and bridge abutments of the cities through which it passes in its course. We know that eddies in the river mark submerged rocks, that sharp curves may be caused by areas too hard for the river to erode, that ledges may cause waterfalls. It is not possible to think of the river without the environment which surrounds it.

Guided by this comparison, we note the *cause* of sensitiveness of living matter of which an organism is made up in the fact that wherever factors of the environment impinge upon the organism, changes in the latter are sure to take place. These factors, forces, or things that cause changes in the life activities of plants or animals are called *stimuli*, and changes in relation between the organism and its surroundings, *reactions* to stimuli. Such responses may be sudden, as the involuntary start which comes as a result of some unexpected noise or the quick withdrawal of one's hand from a hot object, or they may be extremely slow and continuous, as is seen in the gradual turning movements of a plant placed in an area of unequal illumination. The sum total of all the reactions of an organism to the stimuli which impinge upon it constitutes its *behavior*.

Various Kinds of Stimuli

In order to understand what causes behavior, we must analyze the various kinds of stimuli which act upon plants and animals, as follows :

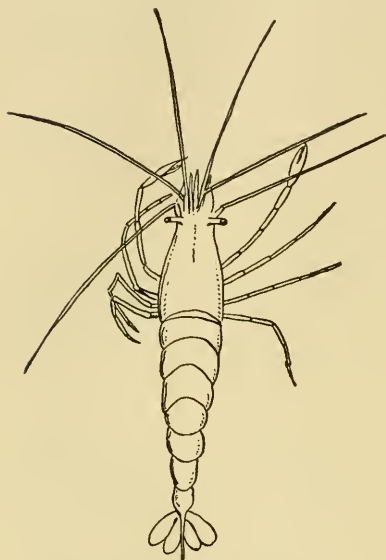
1. *Thermal*, that is, changes of temperature, as extremes of heat or cold.
2. *Photic*, light changes both in direction, intensity, and color.
3. *Chemical*, changes that occur in the concentration of certain substances which may come in contact with the organism. Such changes might be the presence of salts, acids, alkalies, or other substances in the soil, or various types of chemical substances such as are found in the food of animals.
4. *Electric*, changes in the direction and strength of electric currents. Since the modern concept of matter is interpreted in terms of electricity, it must be realized that these changes may have a profound effect on living organisms.
5. *Mechanical stimuli*, such as changes in osmotic pressure within cells, the pull of gravity, changes in pressure of the medium. Contact with various objects, and sound waves, are also important. Many animals and plants respond definitely also to currents of air or water.

In unicellular organisms responses are usually more predictable than in higher organisms because the latter are complex structures in which different parts may be differently affected by the same stimulus. For example, gravity may act negatively on the stems of green plants and positively on the roots of the same plant. While the stem of a plant may be influenced to grow toward light the roots grow away from it. These examples might be multiplied many times.

Tropisms

In 1918 Jacques Loeb, one of the foremost investigators in this country, brought out a book entitled, *Forced Movements, Tropisms, and Animal Conduct*. The author took for his thesis the mechanistic point of view of life. To him, and to other members of his school, living organisms are mechanisms whose activities are directly influenced by the stimuli in their environment, the sum total of behavior being the direct result of their reactions to various stimuli. In a series of convincing experiments, Loeb showed that animals are forced to do certain things because of a purely mechanical effect brought about by the stimuli impinging upon them. If, for example, the common shrimp (*Palaemonetes*) is placed in a trough through which an electric current flows, with its head toward the *anode* pole, the tail at once becomes stretched out. If it is placed with its head toward the *cathode* pole, the tail is bent under the body. In the latter case the animal can only

swim backwards, while in the former case it can only *crawl forward*. In both cases the change in position is caused by the action of the current on the flexor and extensor muscles, which in one case are contracted and the other case extended, thus causing the animal to assume the po-



Position taken by legs of shrimp when current goes laterally through animal, from left to right. (After Loeb and Maxwell.)

Which direction would the animal be forced to take in movement?

sitions mentioned. Experiments such as these give rise to the theory of *tropisms*, which is simply another term for a series of responses of an organism to the various factors of its environment. Tropisms may be briefly classified as *phototropisms*, or responses to light; *geotropisms*, or responses to gravity; *hydrotropisms*, or responses to water; *chemotropisms*, or responses to chemical substances; *thermotropisms*, or responses to temperature changes; *galvanotropisms*, or responses to electricity; *thigmotropisms*, or responses to contact; *rheotropisms*, or responses to water currents; and *anemotropisms*, or responses to air currents.

A tropism is a kind of directional urge. It represents a condition within an organism, resulting from the interaction between its structure

(nervous) and the stimuli of the environment. Loeb explained tropisms as specific irritabilities or sensitivities to stimuli at the surface of the body, and in terms of body symmetry, since corresponding parts on two sides of the body would show the same sensitivities. Noncorresponding parts, according to this theory, would show unequal sensitivities, resulting in directive movements.

Loeb explained his famous example of the reversal of tropisms in a caterpillar by showing that the caterpillar moves toward light when hungry and is irresponsive to light when satisfied. The result is most useful to a caterpillar, because as it leaves its nest when hungry, it is near the surface of the ground and is drawn by light to the tips of the branches where young edible leaves are sprouting, returning to the lower branches when nonresponsive to light.

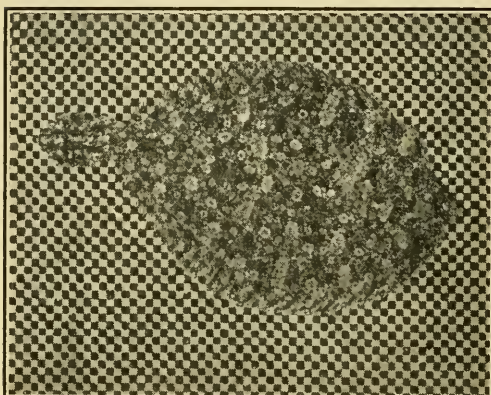
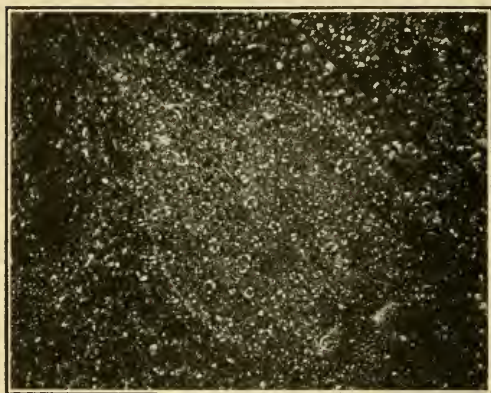
The typical moth is positively phototropic. This is an advantage in its natural environment because it flies at night and gets its food largely from white flowers which are more conspicuous at night. If, however, the factor of artificial light is introduced, the moth flies to its death. This is not because it "thinks" it sees a white flower, but because its eyes, its central nervous system, and its wings are all connected as a unit, so that the animal *has* to turn in flying to the flame not once, but again and again.

Jennings found *Paramecium* equally responsive to paper, silk, or particles of carmine placed in its immediate environment, thus showing a purely mechanical response. It took these foreign substances into its gullet and the material was passed into the body. Such responses are not advantageous. On the other hand a purely thigmotropic response may be advantageous to these animals. *Paramecia* feed on bacteria, which may form raftlike masses. As soon as a *Paramecium* comes in contact with such a mass, its response to this stimulus causes it to remain quiet, while it feeds upon the bacteria. Its sensitivity to other stimuli at this time is decreased, making it seem as if its attention were "fixed upon its meal."

Nature of Responses

The nature of a response to a stimulus depends upon the intensity and nature of the stimulus as well as upon the structure of the part stimulated. The nature of this response may differ greatly. In unicellular organisms the entire cell may move in response to a stimulus, though sometimes there is only a turning or the movement of cilia on one side. If a simple animal such as *Hydra* is touched, withdrawal of the tentacles touched may occur, or, if the stimulus is more intense, the entire body may contract. In plants, responses to stimuli may result in movements caused by differences in osmotic pressure of the cells, or in turning movements brought about by the growth or turgor of certain cells. There may be glandular responses, too, such as the production of nectar in flowers, or the flow of saliva, or the dry mouth of "stage fright" in man. The newt gives off slime when touched, and the gland cells in the skin of a toad exude poison when it is roughly handled.

As a result of response to pressure, gas is secreted into the swim-bladder of some fish. Certain areas in jellyfish or in fireflies become luminous when touched, while some fishes and other animals, such as squid, octopuses, tree frogs, and chameleons, respond to changes of the



Francis B. Sumner

Dr. Sumner's experiments with flounders show a response of the animal to different backgrounds. How would you attempt to account for this?

environment by changing their color pattern. There may even be electric responses to stimuli as seen in the discharge of as much as 300 volts from the electric organ of the electric eel, a shock sufficient to kill a horse. In the higher animals where well-developed organs have been evolved, an organ is usually attuned to one kind of stimulus and responds only to that particular stimulus. The eye, for example, responds to light waves, but to no other ether waves, while the *organ of Corti* in the mammalian ear distinguishes with accuracy between different wave lengths which cause sounds. Thus the nature of responses depends not upon the stimulus, but upon the kind of cells stimulated.

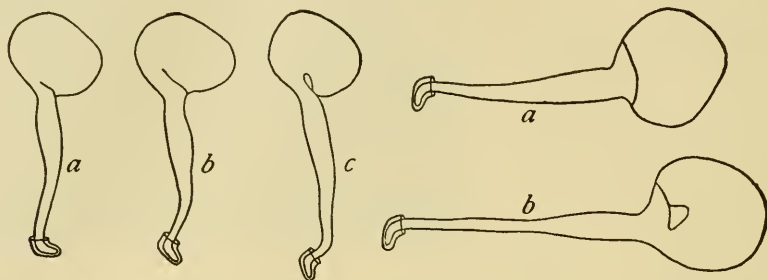
Mechanisms of Response in Plants

It is much easier to show that plants respond to stimuli than to explain how they do. Most of the responsive activities of plants do not, as one author puts it, result in "discriminating movement" so much as in "discriminating growth." If a growing root is photographed every ten or fifteen minutes and these pictures greatly magnified are projected as a slow motion motion picture, the root seems to act like an intelligent "white worm," pushing aside soil particles, avoiding obstacles, and ultimately finding its way to an area where water exists.

In spite of the work of Sir J. C. Bose, the distinguished Indian botanist, who used very delicate instruments to measure the irritability of plants, scientists as a group have not accepted his belief that the transmission of stimuli in plants is by means of a mechanism similar to the nerves of animals. There is no doubt that certain parts of the plant stem do conduct stimuli more rapidly than others, but it is doubtful whether the conducting strands of protoplasm in the sieve tubes of the phloem are actually the areas of special transmission. Experiments have been made in which the stimulus of an electric current can be cut out by the use of anesthesia, just as in the case of the nerves of animals, but since the cells in the area where the stimulus is transmitted are much shorter than the neurons in the animal, transmission is naturally slower and anesthetics have the same effect on living protoplasm in each case. One investigator, Ricca, has shown that a stimulated region of a plant secretes a hormone that travels to the region of response, causing a reaction to the stimulus. Other workers have even shown that if the tip of one plant is grafted to another plant from which the tip has been removed, the stimulus will be transmitted to the responsive region of the latter plant. A number of experiments upon plants indicate that stimuli are transmitted by means of hormones which are carried in the transpiration stream through the vascular bundles. Too little is known at the present time to say with certainty exactly what effect hormones have, but it is quite evident that they do play a part in the transmission of stimuli.

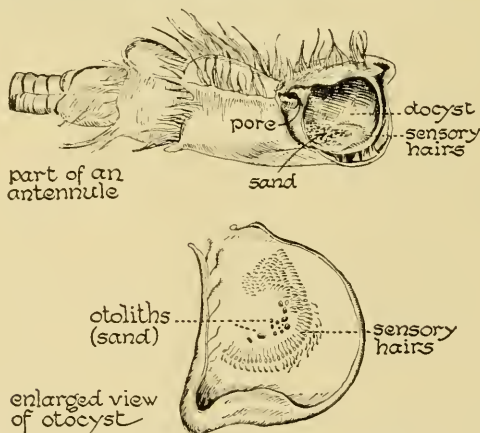
One of the most studied responses is geotropism. Roots are assumed to respond positively to the pull of gravity while stems are considered to be negatively geotropic. Branches and leaves usually grow at right angles to the force of gravity while some roots place themselves at a definite angle to this force. Gravity has been shown to be a stimulus by experiments which either replaced it by some other force, or neutralized its effect. For example, plants are placed on a slowly revolving disk called a *clinostat*. If the plant is revolved horizontally on the disk, which rotates parallel to the long axis of the plant, the roots and stems will continue to grow in the same direction as they did at the beginning of the experiment. Gravity in this case acts on all sides of the plant equally, with the result that there is no change in the position of the plant's organs. In the famous experiment of Thomas Andrew Knight, who worked in the early part of the nineteenth century, plants were placed on a rapidly rotating disk in

which centrifugal force was substituted for gravity. In this experiment the roots grew outward while the stems grew toward the center of the revolving disk, instead of assuming the normal geotropic positions.



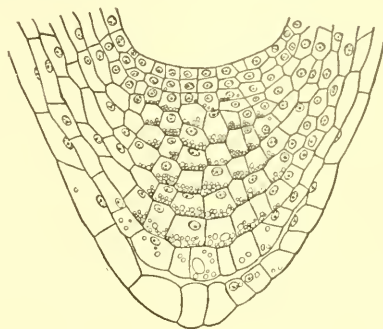
Roots of *Vicia faba* with tips in glass slippers: at left, *a*, *b*, *c*, three stages in the curvature of the same root, 0 to 20 hours; at right, *a*, *b*, two stages of the same root; *b*, 18 hours after being placed in position *a*. (After Czapek.)

Experiments by Czapek, in which the tips of growing roots were placed in glass slippers smaller than those used by Cinderella, show that the region sensitive to the pull of gravity, "at least in certain plants," is located in the last two millimeters of the root-tip. Recent investigators have tried to account for this location of the response. In animals, definite organs which "perceive" gravity are found. Such are the *otocysts* of the crustaceans and the *balancing organs* (semi-circular canals) of higher animals. In the crustaceans small but relatively heavy particles, known as *otoliths*, give the animal its sense



Balancing organs of a crustacean. How do they function?

of position in space when they come to rest on the sensory hairs which line the little pits, or otocysts. A somewhat similar explanation has been advanced to account for the response to gravity in plants. Cells of plants are filled with fluid, but they also have in them various solid bodies, some of which are starch grains, and others tiny crystals of calcium oxalate, or other minerals. It is thought that the movement of these bodies within the cell may give the stimulus for the turning movements attributed to gravity. The twining movement and spiral growth of stems also seems to be related to the stimulus of gravity, for if such plants are placed on a rotating clinostat, the twining movement ceases.



Perceptive region in the root cap of *Roripa amphibia*; with the position of the granules in the cells. (After Némec.)

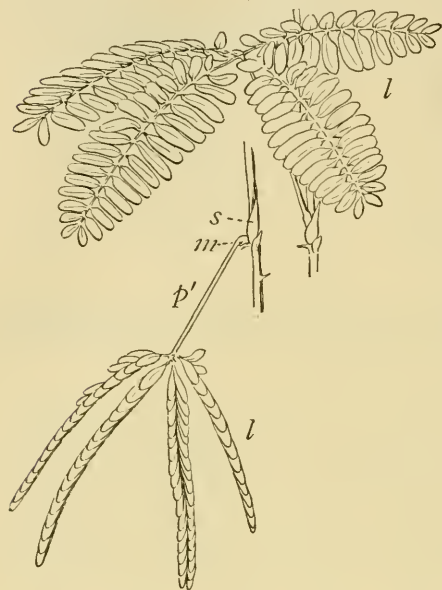
There are many other kinds of responses, but the mechanism of the response is not always clear. Roots travel for long distances toward a source of water. A case is cited in California of a eucalyptus tree which sent out its roots over 100 feet underneath a boulevard, the fine roots ultimately clogging a cement water pipe on the other side



Wright Pierce

The Sensitive Plant (*Mimosa pudica*) before and after stimulation. Time required for reaction can be measured in seconds.

of the boulevard. The Carolina poplar has lost its vogue as a tree for city planting largely because of this habit of clogging drain pipes by the response of the roots to water. The movements seen in the wilting of leaves, or the changes in the position of leaves in bright sunlight



Leaf motility in the sensitive plant (*Mimosa pudica*): above, an open leaf; below, a leaf whose leaflets (*l*) have been closed by mechanical impact; note also that the petiole (*p*) has dropped; *s*, stipule; *m*, pulvinus.

and in slight illumination, are familiar to all. There may even be a quite rapid opening and closing of flower petals, and there are also definite noticeable changes in the position of the leaflets of clover, alfalfa, oxalis, and other plants in the morning and at night. The relatively rapid responses of the leaves of the sensitive plant, *Mimosa pudica*, are all brought about by the functioning of structures called *pulvini*, cushion-like enlargements of the petiole of the leaf at the point of its insertion in the stem. When the leaflets of the large compound leaves of the mimosa are stimulated by heat, pressure, or anesthetics, they tend to droop, the stimulus from the leaflets being trans-

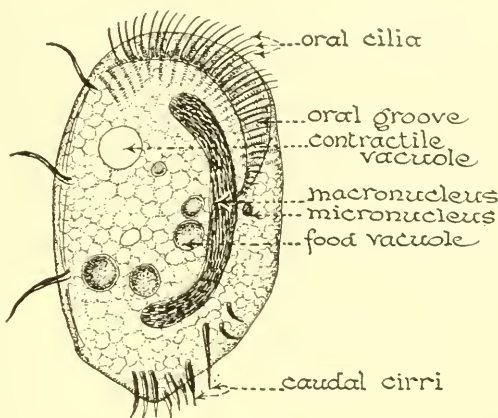
mitted at the extraordinarily rapid rate (for plants) of from one to three centimeters per second. When the stimulus reaches the *pulvinus* where the cells are large and are rich in water, a change in turgor takes place in these cells, with the result that the leaf stalk droops. In some plants there is a rapid and temporary fluctuation in growth on opposite sides of the leaves. This causes a comparatively rapid turning movement, but it is evident that these forces are not in themselves sufficient to explain all the changes that take place in such plants as the Mimosa.

Mechanisms of Response in Animals

The mechanism of the reflex arc has already been described in some detail in the discussion of the various types of nervous systems found

in animals. It will not be amiss, however, even at the risk of repetition, to take up, from the standpoint of function, the effects of some of the forms of animal behavior.

In simple animal cells, such as *Ameba*, the outer portion of the cell is in contact with the stimulus which is transmitted through the protoplasm to the interior of the cell. In cells with cilia, continuations of these structures that reach down into the protoplasm apparently act as organs for reception of stimuli. *Euglena* has a pigmented "eye-spot" which is definitely sensitive to light. In some specialized protozoan cells a *motorium* or co-ordinating center is found.



Euplotes, a hypotrichous ciliate. Note the thickened cilia or cirri by means of which the animal is able to make sudden jumping movements.

In higher forms of animals there are definite receptors in the form of sense cells, organs which act as stimulating centers with nerves serving as conductors to the parts that are fitted for response, the so-called *effectors*. Examples of such effectors are the muscle cells, gland cells, and the cells of such organs as the luminous areas of the fire-fly, and the electric organ of the electric eel. In the nerve net of such animals as *Hydra*, or the jellyfish, apparently no synapses exist between the cells, the nervous system being a tangled net through which the nerve impulse flows. In such a nervous apparatus the nerve activity is slower than in a type of nervous system found in animals like the earthworm. The so-called "ladder nervous system" exists in worms and in arthropods generally, and is seen at its highest development in the insects, where there is a series of units in which the neurons are connected by synapses. Such types of nervous systems are more effective because the nerve impulses travel only in one direction through a neuron, while in the nerve net they may travel in any direction. *Receiving neurons* in the sense organs are found at the surface or in a situation where they may be exposed to stimuli.

Connecting neurons tie up these with the *effector neurons* which stimulate the muscles to contract, or the glands to secrete. The dorsally

a few cells of the
nerve net of
Hydra



ladder system
of a myriapod



system of adult midge
fly



placed vertebrate nervous system is considered the most highly developed type of all. Here centralized function is found at the anterior end of the body in the so-called brain. In the animal series all animals except those built on the radial plan show a very distinct centralization of sense organs (*receptors*) at the anterior end. The organs of sight, hearing, taste, and smell are found in a relatively small area on the head close to the brain. It is easy to see how evolutionary development has brought this about, since it is the anterior end which is constantly exploring for the rest of the

Three types of nervous systems. What are the general likenesses and differences? Which would be called the highest type and why?

animal. Upon the success of this exploratory ability rests the success of the animal in its struggle for existence.

Tropisms, Reflexes, and Native Behaviors

The term *reflex action* has been given to the response which comes from the stimulation of a single reflex arc, a receptor with its neuron leading inward to an effector neuron which in turn causes movement through the effector muscles or glands. In *most* if not all cases, however, there is more than a single series of neurons engaged in the action of the reflex arc. There is always a direct response in the reflex. The response is quite predictable and results in movement of a relatively small part of the animal's body. A tropism, on the other hand, may be considered as a steady response to a continued stimulus. As one writer well puts it, the tropism is "a steady underlying bias in behavior brought about by a constant stimulus." The tropism affects the organism as a whole, the reflex directly affects only a small portion of it. The activities of all animals, but especially the lower forms, are a continual series of reflexes and tropisms.

When reflexes follow one another in an orderly succession involving a chain of reflexes, one step of which determines the next, they are called *native behavior patterns*. That these are inherited patterns is seen in such acts as cocoon-making, egg-laying, or mating behavior, which only take place *once* in the life of the individual.

There have been two lines of evolution in behavior patterns, one culminating in the insects, the other in man. These two groups are the most successful in the animal kingdom. The insect group embraces probably over 625,000 species, while man is but a single species. It is estimated that many insects, particularly the ants, have undergone no significant structural changes since the Oligocene period some thirty million years ago. They are at the summit of their development while man is just beginning. Insects mark the top notch of these native behavior patterns. Their innate stereotyped functions make them, in the words of one writer, "a bag of tricks." Their actions depend upon a series of associations which form a sequence or chain of events. These chain-reflexes in many cases have formed so complicated a pattern that the ensuing actions appear to be intelligent. However, when these actions are carefully analyzed, by means of experiments, they exhibit a far different type of response. The well-known example given by Fabre will suffice to illustrate how such a chain of reflexes works. One of the *Sphex* wasps habitually paralyzes a cricket by stinging it, and then drags it to its nest as food for its larvae. After the female wasp has dragged the paralyzed victim to the entrance of the burrow, she leaves it there and goes inside, apparently to inspect conditions. In his experiment, Fabre moved the cricket a short distance from where it was left and when the wasp came out, finding the cricket out of its original position, she seized it again and dragged it back to the mouth of the nest, and again went in. Fabre removed the cricket forty times, and for forty times the wasp repeated its actions. As Huxley has so aptly said, all she knew was, "drag cricket to the threshold—pop in—pop out—pull cricket in." In this case the initial stimulus that started this whole chain of events was the maturing of the egg in the body of the wasp, and the breaking of a single link in the chain of associations was sufficient to break the sequence of events. Examples of these chain reflexes, which have been called *instincts* for want of a better term, are so numerous that volumes have been written about them. The many fascinating books of Fabre, the intriguing volume on wasps by the Peckhams, the still interesting classic entitled, *Ants, Bees and Wasps*, by Sir John Lubbock, are all worth reading.

Native Behaviors May Be Modified

Although native behavior is usually predictable, there is some evidence that it may be modified under certain conditions. Howes¹ gives such a case. The sphecid wasp places a single paralyzed cicada in its burrow after laying an egg in the body of the unfortunate victim. The burrow is then sealed with earth, the young wasp feeding on the paralyzed insect until the larva pupates. The adult wasp carries the cicada, which is larger than itself, by means of two powerful up-turned hooks on each side of its hind legs. Howes removed these hooks from the legs of a sphecid wasp and after several hours replaced the wasp near the burrow, but close to a cicada which it had previously captured and paralyzed. The wasp paid no attention to the cicada but flew off, shortly returning with another victim which it carried between the first and second pairs of legs. This shows a marked modification of its original instinctive behavior.

The following examples show how in two nearly related species there may be differences in behavior. The mud-dauber wasp builds a small nest of from eight to ten cells, filling each cell with paralyzed insects or spiders which are used as food for the developing young. In filling the cell, Howes found that the wasp averaged one spider for every seven minutes of time until its tenth visit, when it brought a small pellet of mud which it flattened and placed across the opening of the cell. This was not enough to close the cell, so the insect flew away to get more mud. While it was gone Howes removed the spiders and the cell cap. The wasp, upon returning, resealed the cell without examination and without depositing spiders or another egg. In the case of the paper wasp, a near relative, when Howes replaced an unfinished cell with one of papier-mâché the wasp immediately tore the papier-mâché cell down and proceeded to build a proper one. This indicates that the chain of native behaviors in some cases may never be broken without a complete re-acting of the whole scene, while in others modification of behavior which looks like a low-grade intelligence is found.

In considering the insect with its "bag of tricks," all of which can be played expertly but which cannot be changed, we must think in terms of structure as well as in terms of function. Contrast, for example, the strongly built claws, legs, or mouth parts of an insect, or a crustacean, with the hands of a man. The former, each of which

¹ Howes, P. G., *Insect Behavior*, Badger, 1919.

is fitted to perform a very limited number of unchangeable acts, are rigid. The latter, on the other hand, are plastic, extremely flexible and adaptable, capable in some instances of playing a Chopin nocturne, or in others of fashioning the cunning work of a Cellini.

Habit Formation

The patterns of behavior that we call habits are closely allied to native behaviors. If animals can make associations, any act which comes as a result of a contiguity of stimulation and useful association tends to be repeated. If there are many repetitions the performance of such an act becomes more and more certain. In other words, it becomes a habit. It has been said that our lives are bundles of habits. This is particularly true of man, since many of the activities learned in early life, such as walking, learning to drive a car, riding a bicycle, skating, swimming, writing, typewriting, and hundreds of other activities common to this machine age, are habitual.

One object of education is the training of different cerebral areas so that they will do their work efficiently. In learning to write one exerts a conscious effort in order to make the letters at first. Later, the actual forming of letters is done without conscious effort, for by training the act has become habitual.

Conditioned Behaviors

More than thirty years ago the famous Russian physiologist Pavlov began a series of experiments that have changed much of our thinking regarding the fixity of animal behavior. His best known work was done with dogs. It is proven that when food is offered to a dog saliva is secreted. This effect is partly *psychic* and partly mechanical, as can be seen when one thinks of a particularly sour pickle or lemon, or chews dry food. Pavlov found that the dog's saliva, which was normally

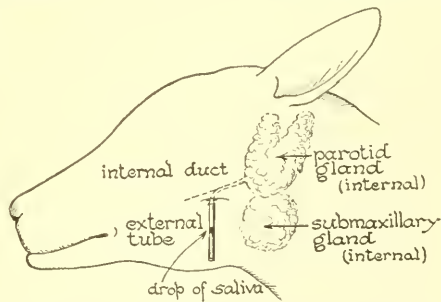


Diagram to show Pavlov's experiment. Under what conditions would saliva be caught in the tube? Explain why he obtained a conditioned reflex.

secreted when the dog saw food, could be caused to flow by the ringing of a bell, or by the presentation of a plate of a given color.

But this behavior was only brought about through the presentation of food many times in succession at the same time or just after the ringing of the bell, or the use of the colored plate, thus forming an association between food and bell, or food and plate. Eventually when food was not presented but the bell rang, or the plate was shown, saliva would flow from the parotid gland just as if food was present. The reflex established originally with food was changed through association of food with bell or plate. Thus Pavlov established a law of the *conditioned reflex*, which may be stated thus: "If a new indifferent external stimulus is many times present along with one which has also a definite response, the subsequent presentation of the new stimulus causes the *reflex* to be given."

Conditioned reflexes have been demonstrated in forms as simple as the Ameba, earthworm, crab, snail, octopus, as well as in higher animals. It is, however, unlikely that conditioning plays a very important part in the lives of lower animals. In the case of fishes, reptiles, amphibians, and vertebrates, the "training" which comes through the conditioning of behavior may play a minor part. In the highest vertebrates, apes and men, conditioning undoubtedly plays a very definite part in the learning process. Experiments made in Pavlov's laboratory have shown that while a dog may take from thirty to one hundred trials before it is conditioned to food, a young child may show the same conditioned effect in from ten to twenty-five trials.

Are Behaviors Adaptive Responses?

It is easy to show that all responses to stimuli are useful to a plant and, therefore, enable it to adapt itself more easily to the environment in which it lives. The turning of stems and leaves toward light, the "seeking" of roots for water, the twining movements of plants are all well-known examples.

When it comes to animals, there are two views of their response to stimuli, one mechanistic, the other adaptive. The first considers the organism to be a machine that responds blindly to the various physical and chemical stimuli which impinge upon it, regardless of the consequence to the organism. This is much easier to see in simple animals than in more complex ones, because in the latter the behavior of the organism is influenced not only by different combinations of stimuli but also by the reinforcement or weakening of stimuli. The behavior of the organism at a given time will be determined, not by a single

stimulus but by the aggregate of all the stimuli which impinge upon it. The stimulus pattern causes the behavior pattern. The fact that organisms behave in a purposeful way and that frequently their behaviors are modified or "conditioned," has given rise to the point of view that behaviors are adaptive.

To understand this philosophy it is necessary to go back to the work of Child. In recent years he has shown that all organisms exhibit a definite polarity. Even in a single-celled organism, polarity is shown not only in an anterior and posterior end, but also in a physiological gradient which extends from the surface to the interior. The protoplasm at the surface exhibits the highest rate of metabolism, the protoplasm near the center the lowest rate. If the organism is cut in two, a new center forms as far away from the surface as possible and a new field of metabolism comes into existence.

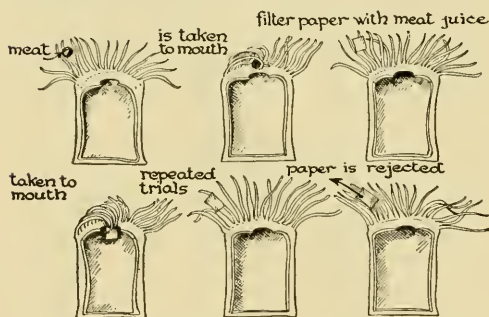
The following test of this metabolic gradient was made with flatworms, animals so simple in structure that they lend themselves readily to experimentation. After removing the head and tail end of a number of worms, the remaining part of the worm was cut into four pieces, as many as a hundred worms at a time being used in the experiment. After sorting the cut pieces into groups of anterior sections, second, third, and fourth sections, it was found that the metabolic rate in these groups was constant, the most anterior group using the most oxygen and giving off the most carbon dioxide. The most posterior group used the least oxygen and gave off the least carbon dioxide. There was thus a chemical gradient of physiological activity correlated with the nervous differentiation of the organism, the latter acting as a physiological unit and not as a cell aggregate.

Physiological gradients are seen everywhere. Eggs exhibit polarity, the potential energy at one end being much greater than at the other. Gland cells are polarized so that they always secrete in a certain direction, while nerve cells in higher animals invariably conduct impulses in only one direction. In embryos, an early polarization takes place and, as we have seen, all animals except radially symmetrical ones exhibit polarity.

The beginnings of behavior in embryonic animals start as mass movements of the organism as a whole. This has been found to be due to the fact that the central nervous system has not grown out into the surface of the body. A new group of behaviorists start with the general thesis that behaviors, such as tropisms, are organized responses to a total pattern of stimuli, the organism modifying its

behavior according to the stimulus pattern it receives. This modification results in a change or *tension* on the part of the organism, leading it toward a goal. This goal may be food, or some other "desirable" situation. Many experiments have been made which indicate that modifications of behavior which result in learning take place very early in the animal scale. Schaeffer¹ made an interesting experiment with Ameba. He put a particle of glass close to an Ameba that had been starved for some time, making the glass vibrate by means of a rod. The Ameba immediately surrounded the glass, forming a food vacuole, but after six minutes expelled the glass. Five minutes later the glass was again presented, and again the Ameba ingested it, this time expelling the glass after three and a half minutes. In a third presentation the glass was only partially ingested and two more trials gave slight food response. All further trials showed the Ameba completely indifferent to the glass. This continued placing of nonedible material in front of the animal set up a tension in the protoplasm which resulted in a modified behavior, causing indifference to the vibrating glass.

In animals which have only a nerve net, modification of behavior is also possible. In the famous experiments of Loeb and of Parker bits



A sea anemone will learn to distinguish between meat and filter paper flavored by meat juice.

of meat were presented to the tentacles of a sea anemone, the meat being passed by the tentacles into the mouth. Then the same tentacles were fed with bits of filter paper which had been soaked in beef juice. At first the animal made no distinction between food and filter paper but after ten trials learned that

filter paper was not food and constantly rejected it. Hundreds of other examples might be given to show that behaviors are modifiable. But if lower animals live in a world of present actions and "have no thought for the morrow," then it is doubtful if this conditioning of behavior means much in the ultimate solution of their life problems.

¹ Schaeffer, A. A., "Choice of Food in Amoeba." *Journal of Animal Behavior*, 1917, Vol. VII, 220-252.

When Are Animals Conscious?

If we accept Loeb's mechanistic point of view, no animals lower than man would be considered conscious. As Professor Hodge once said, "A house fly is about as intelligent as a shot rolling down the board." Once a chain of behavior is set in motion, it continues until the life cycle is completed by egg-laying.

The theory most commonly accepted among psychologists today is that when an animal improves its responses through the use of experience, then it has some degree of consciousness. Just because an earthworm may "learn" to turn to the right instead of the left in a T-tube to avoid an electric shock does not mean that it has either consciousness or memory in the true sense of those terms. Nor does the dog which can be conditioned necessarily have a consciousness of the sound of a bell or of color in the sense that man does. In insects, for example, where there is a highly developed nervous system of a specialized type, the animals live largely in a world of odor. Their perception of food, nest, or surroundings is largely dependent upon odor. Ants recognize each other and their tribal enemies by odor. The male moth recognizes its mate by odor.

We must be careful not to read our own sensations into the responses of simple animals. As Wells, Huxley, and Wells aptly say, "The jelly-fish only pulsates. A sea urchin with its nerve-net has no sense of wholeness." It is a mistake to assume that lower animals live in a world where space and time play a conscious part. The eyes of worms, insects, or most molluscs do not "see" in our sense of the word. The insect may perceive colors and moving objects, but to many animals the world is a world of light and shadow. Three states of existence are probably found, — that of mere reception of stimuli; another, in which objects become stimuli; and in higher animals a perception of space and time. The world of recognized cause and effect is probably open only to the highest animals, such as apes and man. Therefore, consciousness is a very variable term and at most does not mean much to the psychologist.

Emotional Responses

The emotional responses of higher animals are a type of nervous and glandular activity that plays a tremendous part in their lives. Feelings, joys and sorrows, fear, anger, worry, or optimism, how much they govern the life patterns of the average man! Biologically

such activities are closely tied up with hormone activity. Definite changes in the body are recognized as associated with certain emotions. Sudden fright causes the heart to beat faster, the hair "stands on end," the face blanches, and the digestive glands cease their accustomed activity. The biologist sees in these physical accompaniments of the "feelings," changes that hark back to native behaviors, actions that make for self-preservation. Under the stress of unpleasant emotions the glandular activities of the digestive tract are reduced, so that more blood flows to the muscles, thus allowing greater muscular activity. The automatic sympathetic nervous system invokes secretion from the adrenal glands which in turn tune up the sense organs to greater sensitivity and the circulatory and respiratory systems to greater activity, with a resulting increase in oxygen and in food to the muscles. Emotions are evidently self-preserving activities, but they also add and subtract much from the lives of men. The highly emotionalized person who has his "ups and downs" may get more out of life than his lethargic neighbor, but he also suffers more deeply and may make more mistakes in judgment when under emotional stress.

What Is Intelligence?

The term *intelligence* has been much misused, for we are apt to read our own point of view into the actions of lower animals. Psychologists say that an animal is intelligent when behavior is flexible enough to make it profit by experience. Stereotyped functions having a pattern handed down by heredity have been shown to be native behaviors. Patterns of conduct not inherited, but acquired by many repetitions, are habits. The intelligent act shows choice. It involves analysis of a situation and the comparison of past experiences in relation to the present, that is, there must be memory or a record of past events. In addition, the intelligent act also involves a synthesis with past experiences built up with the aid of memory and imagination. Intelligent animals show a certain amount of insight. Intelligence involves the solving of problems, in other words, the directional mind set toward a goal.

Intelligence in animals appears to be correlated with a definite development of the cortical layer of the cerebrum. Although the size and weight of the brain have little to do with intelligent action, the size of the cerebrum in relation to the rest of the brain is definitely correlated with intelligence. More than this, the number of convolutions in the surface of the cerebrum, with a consequent increase

in the number of cortical brain cells, has a decided correlation with the degree and kind of intelligence that an animal shows. A comparison of the brains of normal with those of feeble-minded individuals shows that in the latter the number or depth of the cerebral convolutions is much less than in the former, thus giving an anatomical evidence for differences in intelligence in man.

As one of the authors¹ has said,

“With an increase of cerebral function the instinctive reflexes take more and more to the background, and therein is a great distinction between ‘lower’ animals which are largely at the mercy of their environment and heredity, and the ‘higher’ animals, which to an increasing degree have risen above environmental conditions, and become more and more ‘the captains of their souls.’ The most prized possession of mankind is the ‘capacity for individuality,’ yet even what passes for ‘free will’ has its basis in the neurons and reflexes built up in the brain, that after all must be regarded as the mechanism *through which* consciousness, memory, imagination, and will are affected, rather than as the seat of these manifestations of intellectual life.”

Types of intelligence differ widely in the animal scale. The so-called “Gestalt” psychologist would consider modified or conditioned behavior as evidence of some degree of intelligence. Perkins and Wheeler have shown that goldfish could be trained to make correct responses to light of various intensities even when the absolute intensities of the lights were changed as well as their positions. Scores of similar experiments performed with higher animals could be cited to show adaptative configurational behaviors. If, however, we take the criteria given in the above paragraphs it would seem that memory and a synthesis of previous action are necessary to the possession of true intelligence. The “hold-up” bear of Yellowstone Park appears to be intelligent when it lumbers out of the forest and holds up the passing autoist for candy. It simply associates the moving cars and their contents with sweets. Probably chance started it on its nefarious career. A dog taught to do certain tricks seems intelligent but has simply formed associations between the food given as a reward and the act learned. A dog which welcomes its master after a long absence probably does not remember or have a deep attachment for its master, but simply responds to a blind though increasing urge brought about by a stimulus pattern in which associations exist between master and food, or some other goal.

¹ From Walter, H. E., *Biology of the Vertebrates*, p. 631. By permission of The Macmillan Company, publishers.

Intelligence of Apes

Because of their relationship to man, the higher apes have been the source of much fruitful experimentation of late years. Köhler¹ has demonstrated that the chimpanzee shows evidence of emotionalized response as well as a comparatively high degree of intelligence. A chimpanzee shows emotion not only by actions, but also in facial



Yale Laboratories of Primate Biology

Chimpanzees are the most emotional as well as intelligent of the apes.

expression. The ape jumps up and down to show excitement, knocks its head on the floor of the cage when unable to solve a difficult problem, or looks vacuously into space and smiles when lost in contemplation of some object that interests it. Yerkes² shows that chimpanzees have wide differences in emotional or intelligent conduct. One may be gloomy, another happy, one lethargic, another active, one dull mentally, and another bright. They may be as temperamental as some human beings or just as stoical. They also show great differences in mentality and like man have their "off" days.

Köhler describes one series of experiments which show that apes have intelligence to solve problems difficult enough to test the ingenuity of a young human child. The ape Koko was the subject. In his cage was placed a box and from the top of the cage a banana was suspended well out of reach. The ape first tried jumping for the

¹ Köhler, W., *The Mentality of Apes*, Kegan, London, 1924.

² Yerkes, R. M., and Learned, B. W.: *Chimpanzee Intelligence and Its Vocal Expression*. Williams and Wilkins Co.

fruit, but finding this did not work, approached the box and gave it a push toward the food, looking meanwhile at the banana. Dr. Köhler then made the goal more interesting by adding a piece of an orange. After a brief pause, Koko went back to the box, pushed it vigorously until it was directly under the fruit, then climbed up on the box and got his reward. The same problem was given Chica, another ape. This was solved successfully several times until one day her companion Teserca was resting on the box. While this was happening Chica jumped in vain for the fruit, finally giving up in despair though not attempting to use the box. Presently Teserca got down from the box. At once Chica dragged the box under the fruit, climbed up, and got her reward. Evidently the box on which Teserca was resting meant to Chica something to "rest on" and not until the box alone was seen with the fruit did it mean "something with which to get the fruit." This simple problem was made more difficult by raising the fruit to a greater height and adding three boxes which had to be piled one on the other before the fruit could be reached. Such a problem was solved by Sultan, an ape of *unusual intelligence*. Yerkes¹ made a similar experiment with the gorilla Kongo in which three boxes had to be stacked in order to reach food. A year after the successful solution of this problem, the gorilla was furnished with a similar problem, the three boxes being of slightly different size. The problem was solved immediately, thus showing evidences of memory.

The most difficult problem of all was solved by Dr. Köhler's ape Sultan. Food was placed just out of reach outside the bars of the cage and Sultan was given two sticks, one of which would fit into the other. Sultan made a good many useless and rather stupid movements before he finally "got the idea" with the aid of the experimenter, who had put one finger into the hole of one stick while holding the stick close to the animal. Sultan, after playing with the sticks, got the two sticks in a straight line and at once pushed the thinner one into the opening of the thicker one. Once having made a long pole with the two sticks, he immediately drew the banana into the cage and was so well pleased with his performance that, without waiting to eat the fruit, he proceeded by means of the double stick to pull in other pieces of fruit. The second time the experiment was tried Sultan almost immediately stuck one stick into the other and got the fruit. In a later experiment he was given two similar sticks the smaller of which was a little too large to go into the hole of the latter.

¹ Yerkes, R. M., "The Mind of the Gorilla." *Comp. Psy. Mon.*, 1928, Vol. V, No. 2.

Sultan chewed the smaller stick down into a wedge and then, inserting it into the larger hollow stick, proceeded to get the fruit. This is a degree of intelligence such as might be seen in primitive cave men who chipped stones to make weapons, or hollowed out trees to make canoes.

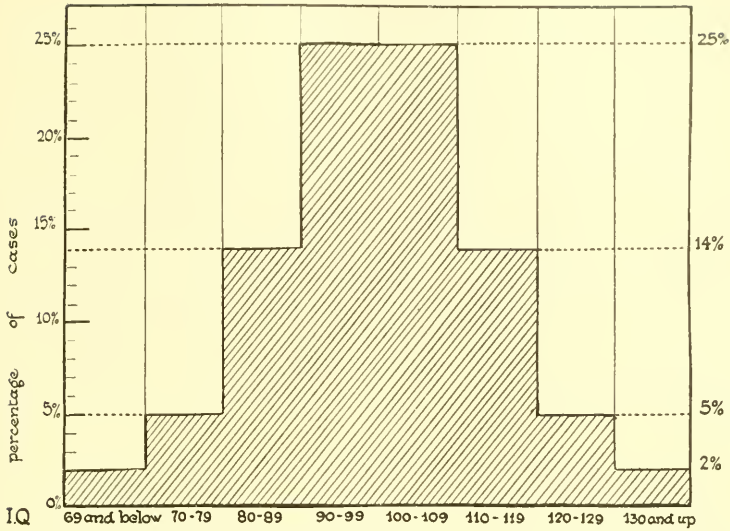
Intelligence in Man

Man, however, is a long step above the ape because he not only can do things that the ape can, but in addition, he has memory which enables him to make complex abstractions and to think of objects and things which are not present. This ability to form complex abstractions and to use them in thinking are things that an ape never could do. As Herrick¹ has well said, "The chimpanzee does not know the meaning of $Y^2 = 2PX$, and he *never can find out*." In addition, man has a tool which the apes cannot use, and that is *language*. One ape has been taught a very few words, but it is doubtful whether these words have any meaning to him. The reader of these lines not only can see the printed word, but can understand the meaning of the symbols employed and can express it in terms of speech. He has traveled a long way further than the apes because he can read, write, and speak.

The Measurement of Intelligence

Most young people today hear a good deal about "I. Q.'s." Numerous tests have been devised which are supposed to measure the intelligence of the human being. The experts who prepared the tests have established norms, or average scores, for different ages. The I. Q., or *intelligence quotient*, is found by establishing a ratio between the *mental age* (M. A.) and the *chronological age* (C. A.) of the subject. If, for example, a child's chronological age is 9 and he makes a score which is that of a child of 10, his I. Q. is found by dividing his mental age (M. A.) by his chronological age (C. A.) and multiplying by 100. In this case he would have $\frac{10}{9} \times 100$, or an I. Q. of 111. An I. Q. of from 90 to 110 is about normal. If a person has over 140 I. Q. he is considered to be a genius, only about 1 per cent of all persons falling in this group. A glance at the chart shows the normal distribution of intelligence as found by testing large numbers of people. While the tests now used are far from perfect, testing factual knowledge rather than ability to think, they do indicate in most cases intelligence with reference to the subject tested, and so fulfill a practical purpose.

¹ Herrick, C. J., *Brains of Rats and Man*. Univ. of Chicago Press, 1925.



Distribution of intelligence in school children. I. Q.'s are shown below graph.

SUGGESTED READINGS

Caldwell, O. W., Skinner, O. E., and Tietz, J. W., *Biological Foundations of Education*, Ginn & Co., 1931. Chs. XIV, XV.

An elementary but valuable text.

Köhler, Wolfgang, *The Mentality of Apes*, Harcourt, Brace and Co., 1926.

Fascinating reading.

Paylov, I. P., *Lectures on Conditioned Reflexes*, International Publishing Co., N. Y., 1928.

Authoritative and based on experimental evidence.

Walter, H. E., *Biology of the Vertebrates*, The Macmillan Co., 1929. Chs. XIX, XX.

A well-established authority easily read.

Wells, H. G., Huxley, J. S., Wells, C. P., *The Science of Life*, Doubleday, Doran & Co., 1934. Book VIII.

Interesting discussion of consciousness in animals.

Wheeler, R. H., and Perkins, T. H., *Principles of Mental Development*, The Thomas Y. Crowell Co., 1932. Chs. III, V.

An excellent exposition of gestalt psychology.

Yerkes, R. M., and Learned, B. W., *Chimpanzee Intelligence and Its Vocal Expression*, Williams and Wilkins Co., 1925.

Yerkes, R. M., and Yerkes, A., *The Great Apes*, Yale University Press, 1929.

Both of Dr. Yerkes' books give the latest experimental work on the emotional and mental life of the apes.

XVIII

CHEMICAL REGULATORS

PREVIEW. Chemical co-ordination · Regulators of digestive processes · Regulators of general metabolism: Adrenals, thyroid, parathyroids, pancreas · Growth regulators: Thyroid; gonads and pituitary; pineal · Reproductive organs as regulators · The master gland or "generalissimo," the pituitary: the anterior lobe, growth stimulation, gonad stimulation, lactation hormone, thyreotropic hormone, adrenotropic hormone, blood sugar raising principle, fat metabolism-regulating principle, parathyreotropic principle; the intermediate lobe; the posterior lobe · Suggested readings.

PREVIEW

Co-ordinating devices are necessary as soon as cells become grouped together in large enough masses to isolate the inner ones from external stimuli. As the cell mass increases in size, there is a tendency for greater division of labor to be developed, and we find organisms evolving with special tissues to perform specific functions. These tissues in turn are woven into more complex systems that call for a still greater division of labor.

Probably the chief co-ordinating mechanism which keeps the organism in touch with its external environment is the nervous system. Even the primitive nerve net of the coelenterates serves quite adequately in this capacity, while the linear type of nervous system with its more highly specialized co-ordinating centers furnishes a more complex and efficient mechanism in the higher forms. There is another equally important, though far less thoroughly understood mechanism that acts as an "internal co-ordinator," since both nervous and chemical correlation is necessary to secure a symmetrical development and orderly functioning of the related parts.

The study of chemical co-ordination is a field literally bristling with thousands of unanswered questions and holding promise of becoming one of the most productive phases of modern physiological and medical research. Within its pages are already told some of the most thrilling tales of intellectual adventure one could hope to encounter. Only a few of these will be enumerated, but we might well seek an answer to such questions as: What are the controlling devices of the body for producing and regulating normal growth?

What starts and governs the changes in voice and body that accompany the maturing of reproductive systems? What is the explanation of that last little ounce of strength which enables a sprinter to put on the final burst of speed? How can such correlation be possible without the existence of a "master mind" for the body? Answers to these questions will be found in the pages that follow.

Chemical Co-ordination

Our knowledge of chemical regulation of the body is far from complete. Workers in the field of endocrinology, as in other fields, are continuously pushing back the frontiers of ignorance, at best a slow process. Nevertheless, each year new excitants, or *hormones*, are discovered, their effect noted, and their refinement or synthesis accomplished. Rarely there occurs the discovery of the existence of a new and hitherto unsuspected gland that produces one of these hormones. Thus far we know quite definitely that the thyroids, parathyroids, pituitary, gonads, liver, placenta, adrenals, pancreas, the mucosa of the stomach and intestine, and possibly the pineal and thymus glands, function as ductless or endocrine glands. In some instances more evidence is needed, but on the whole a majority of scientists are in agreement regarding this list.

Early zoologists, including such leaders as Johannes Müller and Jakob Henle, failed to attach enough significance to the ductless glands. According to Rogers,¹ the former stated that "the ductless glands are alike in one particular—they either produce a change in the blood which circulates through them, or the lymph which they elaborate plays a special rôle in the formation of blood or chyle."

Probably the first experimental study in endocrinology was made by A. A. Berthold of Göttingen in 1849 when he began a study of the results following the removal of the testes of fowls. Shortly after this Claude Bernard, Addison, and Brown-Sequard made significant contributions. The first of these investigators worked on the liver, while the other two studied the adrenals. Brown-Sequard actually extirpated the adrenal glands and noted that the accompanying weakness and death could be prevented by transferring blood from a normal animal to the one from which the adrenals had been removed.

From the physiological point of view, endocrine glands may be divided into five large groups as regulators of: (1) digestion; (2) general

¹ Quoted by permission of the publishers from Rogers, C. G., *Textbook of Comparative Physiology*, p. 361. McGraw-Hill Book Company, 1927.

metabolism; (3) growth; (4) reproduction; and (5) the master center which serves as the "generalissimo" of all the endocrines. Such an arrangement means that a gland which produces more than one hormone may have to be considered in more than one category.

Regulators of Digestive Processes

Little can be added to the description of the hormone *secretin* except to point out that physiologists are somewhat uncertain as to whether the hormone is first produced as an inactive substance called *prosecretin*, or as the active agent known as secretin. The action of this internal co-ordinating mechanism may be seen, for example, in the secretion of the pancreatic juice which is always poured at apparently just the proper time into the small intestine. At first, this co-ordination was believed to be due to some sort of undiscovered nervous reflex mechanism that was stimulated as the food passed a given point. This interpretation was discounted by two prominent English physiologists, Bayliss and Starling, who in 1902 showed that it is the passage of the acidulated food past the pylorus into the upper part of the small intestine (*duodenum*) which stimulates the production of a hormone, secretin. This substance is absorbed by the blood and carried throughout the body, the portion reaching the pancreas furnishing the necessary stimulus to effect the release of its digestive enzymes.

Regulators of General Metabolism

Adrenals

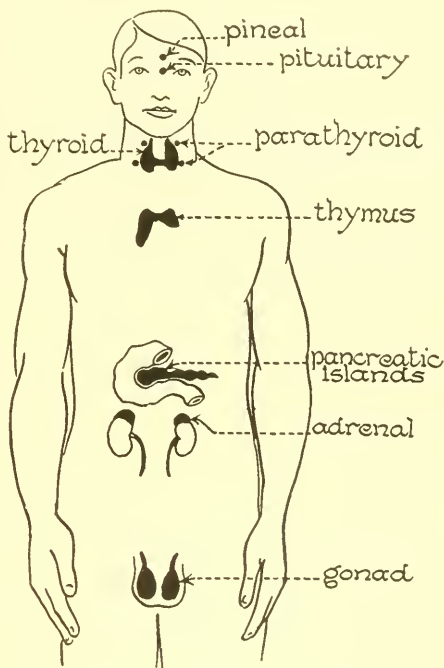
The paired adrenal gland is composed of an outer *cortex* and an inner *medulla*, each part having a different embryonic origin and producing a different hormone. In the lower vertebrates the cortex is represented by an elongated mass of glandular tissue called the *interrenal*, lying between the kidneys and derived embryologically from the lining of the body cavity. The medulla on the other hand is at first a separate structure, composed of so-called *chromaffin cells*, which have their origin in the nervous tissue of the autonomic nervous system. In the higher vertebrates the interrenal and the chromaffin cells become incorporated to form the adrenal gland.

The outer portion, or the cortex of the adrenals, secretes a hormone known as *cortin* which has been proved to be essential to life. If

there is a deficiency of this hormone in the human body heart action slows down, the skin becomes discolored, and the vital energy is overcome by a growing, and usually fatal lassitude, symptoms characteristic of Addison's disease. Biologists and the medical profession were led to this conclusion as to the effects of adrenal hormones through numerous observations and experiments. Swingle, of Princeton, recounts how cats with extirpated adrenals barely survived eight to ten days. During this time their temperature fell six to seven degrees. Yet such animals, at the brink of death, were saved and restored to apparent health within seventy hours by the subcutaneous injection of beef cortin.

Cortin appears to have another property, namely, to stimulate the development of the sex organs. This has been shown by a series of experiments on young male rats, in which the injected animals showed a much more rapid growth of the sex organs than the controls. These studies suggested that the occasional precocious sexual development of young children may be due to an over-enlargement of the adrenals through the presence of a tumor either in the cortex of the gland or in the pituitary gland which largely regulates general endocrine balances. Young girls under similar conditions develop masculine characters. More or less complete cases of the reversal of secondary sexual characteristics in women are on record, in a few of which the removal of tumors involving the adrenals has restored a normally characteristic feminine condition.

The secretion of the medulla or inner portion of the adrenal gland has been known to science for some time as *adrenin* or *epinephrine*. This hormone was first isolated by Takamine in 1901 and has since been



The location of the ductless glands.

synthesized. Its effect is very interesting. It is known that small amounts of adrenin are being continuously secreted and passed into the blood stream to have an effect upon the involuntary muscles of the body. In cases of emotional excitement there is an increased secretion of adrenin, in consequence of which there results a more rapid heartbeat, together with an increase of blood flow and of the glucose output from the liver. This in turn brings about greater efficiency of the muscles and so increases the capacity for work. If this portion of the gland is not operating normally such symptoms

as muscular fatigue, cold hands and feet, sensitiveness to cold, mental indecision, and sometimes collapse and heart failure ensue.

Adrenin is efficacious in relieving severe bronchial spasms during attacks of asthma and it has also been successfully used to mitigate the distress caused by hives and by hay fever.

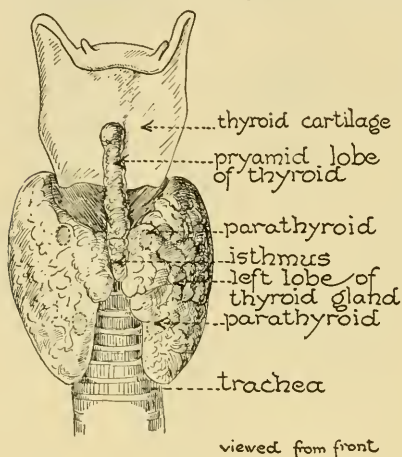


Diagram showing the location and relationship of the thyroid and parathyroid glands.

of the digestive tract. In man the thyroid is definitely bilobed and in cases of goiter may be considerably enlarged.

The secretion of the thyroid gland, *thyroxin* ($C_{11}H_{10}O_3NI_3$), was first isolated by Kendall in 1914 and later improved isolation methods gave $C_{15}H_{11}O_4NI_4$ (Harrington, 1926). Under normal conditions but little of this substance is secreted at a time, in evidence of which is the fact that three and one-half tons of fresh thyroid glands are necessary to produce 36 grams of crystalline thyroxin. This substance regulates the rate of the transformation of energy in the body, thus controlling the metabolic rate. Its potency is almost uncanny, as is evidenced by the fact that one milligram of thyroxin produces a two per cent increase in the total oxidation of a resting adult body.

One concept of the rate of metabolism in the human body may be secured through the basal metabolism test, a device to measure the

Thyroid

Some sort of thyroid gland is present in all of the vertebrates. In every instance it arises as an outgrowth from the pharyngeal region and is, therefore, a derivative

oxygen-carbon dioxide balance, which determines the amount of energy required to keep the body alive, maintain its temperature, muscle tone, rate of breathing, and heartbeat. It has been conclusively shown by a sufficient number of studies that a comparison of people who have been placed under similar conditions may be made, and it is now possible, as a result of these tests, to gain a highly accurate idea of the metabolic rate of different people, and so to detect an over- or under-activity of the thyroid gland. Both conditions are abnormal, indicating rather serious metabolic maladjustments.

If the thyroid is over-active, a person so affected usually has a high basal metabolic rate. Such a person finds his combustion rate speeded up and is a heavy eater, but at the same time that he burns his food products rapidly, he gradually becomes weaker and weaker.

Evidence of a high metabolic rate shows further in nervousness and irritability. The individual is also characterized by protruding eyeballs, an increased and more irregular heartbeat, as well as a higher temperature, insomnia, and general nervousness, which in advanced cases may seriously undermine both the mind and health. This general picture of overactivity is typically associated with the variety of *goiter* known as *exophthalmic goiter*.

Another type of goiter, "common goiter," is frequently encountered in regions where there is a material lack of iodine in the water and soil. In such cases there is an insufficient supply of thyroxin secreted, which is sometimes due to a decrease of iodine in the chemical composition of the thyroxin molecule. Nature apparently endeavors to compensate for this by increasing the size of the gland with rather



New York Academy of Medicine

An example of a goiter. What type is it?
What caused it?

grotesque results. Fortunately this condition may be alleviated in the early stages by the addition of iodine to the diet, or in advanced cases, by extirpation of a portion of the gland.

Occasionally an individual gives evidence of an underactivity of the thyroid gland. In such a case, the amount of thyroxin produced by the gland is actually decreased. Well-defined and characteristic symptoms result. Ingested food is not utilized, with the result that the excess is soon deposited as fat, and definite obesity becomes visible. Certain other symptoms are quite characteristic, as a slowing down of the mental and nervous activities, which may result finally in feeble-mindedness or imbecility. If the thyroid gland be hereditarily defective or non-functional a lamentable condition known as *cretinism* develops. In such cases skeletal development is arrested and a stunted misshapen individual results since normal growth becomes impossible. This condition is alleviated by administering thyroxin.

Parathyroids

The parathyroid glands, likewise outgrowths of the pharyngeal region of the body of nearly all vertebrates, vary slightly in number and position with the form under consideration. In man, there are normally four parathyroid glands having a total weight of not over 0.4 gram. Nevertheless, they persist during life and are now known to play a very important part in maintaining the calcium balance of the body, and by means of it, the irritability of the cells. The active hormone of the parathyroid glands was demonstrated by Hanson in 1925 and later isolated by Collip.

While the exact nature and method of the functioning of these glands is not thoroughly understood, it is known that their removal is usually fatal. The first effect of the removal of these glands is that the calcium salts are reduced and the threshold of stimulation thereby lowered; the peripheral nerves and muscles of the organism become more irritable and the various reflexes become extreme. Severe muscular contraction, or *tetanus*, finally results and the death of the organism usually ensues unless calcium is added to the blood. This may be done by the injection of the hormone or solutions of calcium salts.

Pancreas

While the pancreas has long been recognized as a gland secreting various important digestive enzymes, it was not until 1889 that it

was shown to have an equally important rôle as a ductless gland, producing hormones. Von Mering and Minkowski showed that its extirpation was followed in all cases by the appearance of sugar in the urine. Evidence has accumulated indicating that the oval or spherical *islands of Langerhans*, that are embedded in the pancreatic tissue, are the source of the hormone now called *insulin*, which regulates the sugar metabolism of the body.

The story of the long struggle of scientists to demonstrate the existence of this hormone is a fascinating one. Banting, Best, and Macleod¹ in 1921 gave the first successful demonstration of the isolation of insulin. We now know that the general physical and mental condition of people suffering from diabetes can be markedly improved through the administration of this hormone. While the exact nature of the reaction is not fully understood, it is certain that the amount of sugar in the blood stream is reduced sharply after the injection of insulin.

Growth Regulators

Thyroid

One must think of the thyroid as a gland with a dual function. We have already noted the effect which the secretions of this gland have upon general metabolism. The second effect is its influence upon growth. When the thyroid is removed in young dogs, for example, a retardation of growth occurs in a few weeks. These experiments substantiate observations made upon children with congenital lack of thyroid.

Gonads and Pituitary

As will be noted in more detail later, these glands are both associated with growth, and play an important rôle in the normal development of the individual.

Pineal

Although the function of the pineal gland is not clear, it should be mentioned at this point. It is a small body which appears in nearly all vertebrates as an outgrowth from the roof of the 'twixt-brain (*diencephalon*). The pineal body reaches its greatest development in man at about the seventh year. After that age, and particularly

¹ Banting, Best, Macleod. *Am. Jour. Physiol.*, 59: 479. 1922.

after puberty, it undergoes involution and finally disappears, its place being taken by fibrous tissue. While there is some evidence that extirpation of the pineal gland accelerates the development of the sexual organs of the male, as found in experiments on the guinea pig, its functioning is still a moot question.

While the *thymus* has long been a subject of controversy, it now appears likely to many students that this gland will not prove to belong to the endocrine group.

Reproductive Organs as Regulators

It has been known for many years that the gonads are structures in which are produced the eggs and spermatozoa that are essential to reproduction in most forms of life. However, scientists have learned within comparatively recent years that the reproductive organs function also as ductless glands, producing hormones associated with the development of those features known as *secondary sexual characters*. One group of these hormones, though partially under the control of that "generalissimo" of the endocrines, the pituitary, is really responsible for the normal cyclical functioning of the sex glands. Besides producing eggs and sperm, the ovaries and testes play a vital part in the development of those mental and physical characteristics which constitute maleness or femaleness. The existence of some regulatory mechanism has been clearly demonstrated in various animals by the removal of the sex glands and the subsequent failure of certain secondary sexual characteristics to develop. Numerous examples might be cited. Male deer (*Cervidae*), for instance, are typically adorned with antlers that are annually renewed. A young castrated buck fails to grow antlers, thus suggesting that the key to this phenomenon lies in the production of some secretion of the testes.

Many other experiments, performed in recent years upon the lower vertebrates, tend to support the idea that such secretions are indispensable to the proper development of many male and female characteristics. When emasculated male rats or guinea pigs are given ovarian transplants, the skeleton and hair soon begin to resemble those of a female and before long the mammary glands enlarge to functional size. These results suggest that the effect is due to something secreted in, or by, certain cells of the transplanted gonad.

Other experiments indicate that the hormones of one sex dominate expression of the other sex. Such a case is that of the "free-martin,"

which is a sterile female calf, born with a normal male twin. Lillie discovered in these instances that there was a fusion of the embryonic circulations between the twins and that, since the male gonads develop before those of the female, the male hormone appeared first in the united fetal circulation and not only interfered with the growth of the ovary to such an extent as to cause sterility, but even caused a tendency toward the assumption of secondary male characters.

Evidence relating to a second type of secretion associated with the rhythmical recurrence of ovulation in the female of all vertebrates leads to the belief that in mammals at least two ovarian hormones occur, — one derived from the *follicular cells* surrounding the egg before it escapes from the ovary, and the other from the mass of cells, or *corpus luteum*, that fills the follicle after rupture.

The cells of the follicle secrete a hormone known as *oestrin* into the follicular fluid. This substance has the dual function of initiating some changes in the female and completing other reactions. *Oestrin* is secreted by the ovaries of all vertebrates which have been studied so far. It is a growth-promoting hormone which governs the development of the secondary sexual characters, including the reproductive tract of the female, while the *corpus luteum*, as known at present, is really a mammalian gland which has appeared in association with lactation and viviparity. The corpus luteum hormone, *progesterin*, prepares the uterus for the reception of a fertilized egg, and if one does not appear the corpus luteum involutes, the uterus returns to a resting condition, and a new cycle is started. Progesterin quiets the uterus by inhibiting its rhythmic, spontaneous contractions. In the strict sense the corpus luteum may be regarded as a gland of pregnancy. Several interesting experiments have been performed on various mammals. It is well known that the mating instinct is lost when a normal female is spayed (removal of ovaries). Allen and Doisy were able to produce characteristic cyclical changes in the genital tract of spayed rats and mice by the injection of the hormone from the follicular fluid.

The interstitial cells of the testes evidently yield hormones which produce secondary sexual characters in a castrated male. Much work still remains to be done on this point.

The Master Gland or "Generalissimo," the Pituitary

The pituitary gland, or *hypophysis*, might well be regarded as the commander-in-chief of all the endocrine glands. Embryologically the

anterior part of the gland arises as a dorsal evagination (*Rathke's pocket*) from the buccal ectoderm, while the posterior part develops as a downward outgrowth (*infundibulum*) from the portion of the brain (*diencephalon*) lying directly over the mouth. The anterior outgrowth in man finally produces the *anterior lobe*, a small *intermediate lobe*, and a thin layer extending to the brain as the *pars tuberalis*, while the posterior portion forms the so-called *posterior lobe*, or *pars nervosa*.

The Anterior Lobe

There appears to be fairly good evidence of the existence of at least five and possibly eight hormones produced by this portion of the pituitary gland. It is probable, since the histology of the gland indicates remarkably little diversity of tissue, that the substances produced are very closely related chemically.

A. GROWTH STIMULATION. If overactivity of this portion of the gland occurs when young, giants will result. On the other hand a similar overactivity arising when adult, results in excessive growth of the bones of hands, feet, and face — a condition known as *acromegaly*. The intraperitoneal injection of fresh anterior pituitary extracts resulted in the production of giant rats. Additional evidence has been secured through the autopsies of various giants, who showed a greatly enlarged pituitary.

B. GONAD STIMULATION. During comparatively recent years it has been shown that anterior pituitary implants will produce sexual precocity in sexually immature mammals. This operation has been performed on all of the more common laboratory mammals, including cats, dogs, and monkeys, and thus far holds for all vertebrates studied. In the female such implants stimulate the development of both follicles and corpora lutea, which are associated with the growth of the female secondary sexual characters. Implants in the male stimulate the development of the semeniferous tubules and interstitial tissue correlated with the growth of male secondary characters. These effects, as determined by hormone isolation, are due to two hormones secreted by the anterior pituitary, — one which stimulates the growth of follicles in the ovaries and tubular growth in the case of the male, and the second which produces the formation of the corpus luteum and the secretions of the interstitial cells of the testis.

C. LACTATION HORMONE. Knowledge of the existence of this hormone is comparatively recent. Various workers reported that

they were able to induce lactation in spayed, virgin rabbits, which had developed mammary glands prior to the operation, through the injection of a substance secured from the anterior pituitary. Some years later *prolactin* was extracted in an impure form which, while not causing development of the mammary gland, nevertheless brought about the onset and continuation of the secretory phase. Prolactin was effective after castration.

D. THYREOTROPIC HORMONE. While many investigators have demonstrated a close relationship between the pituitary and the thyroid gland, it was not until 1927 that the pituitary gland of the rat was removed to show that the thyroid is dependent upon this structure for stimulation. In 1933, a purified extract under the name of the *thyreotropic hormone* was prepared.

E. ADRENOTROPIC HORMONE. It was shown in 1930 that if the anterior lobe of the pituitary is removed in rats atrophy of the cortex of the adrenals follows, although normality may be restored by injecting pituitary extracts. Later Houssay and his co-workers showed that the active agent in such experiments is a product of the anterior lobe, also proving the existence of this *adrenotropic principle*.

Most biologists now concede the existence of these five hormones from the anterior lobe of the pituitary gland. Evidence is rapidly accumulating which supports the idea of the existence of three more, F to H.

F. BLOOD SUGAR-RAISING PRINCIPLE. It has been previously shown that the removal of the pancreas results in the appearance of sugar in the urine, that is, experimental diabetes is produced. Overactivity of the pituitary, as acromegaly, for example, is usually associated with *hyperglycemia* (over the normal amount of sugar in the blood) and *glycosuria* (sugar in the urine). Furthermore, a normal animal develops the same condition when injected with anterior pituitary extracts. Now, when the hypophysis is removed hypoglycemia results and the animal is very sensitive to insulin. Also it has been shown that if both the anterior pituitary and the pancreas are removed the experimental diabetes resulting from the loss of the pancreas is greatly decreased. It is apparent, then, that in the absence of the pancreas the anterior pituitary tends not only to increase the blood sugar but also to make the animal sensitive to insulin. This clearly indicates that there is a balance between these two glands. It might be added that extracts of the anterior pituitary increase the blood sugar in the absence of the pancreas, thy-

roids, adrenal medulla, and sympathetic system. It appears quite conclusive, therefore, that the action of the anterior pituitary hormone is at least partially direct.

G. FAT METABOLISM-REGULATING PRINCIPLE. Several groups of experimenters have produced evidence, since 1930, that the anterior lobe of the pituitary gland also produces a hormone that regulates the metabolism of fats in the body.

H. PARATHYREOTROPIC PRINCIPLE. While the evidence is not irrefutable there are some grounds for believing that the control of the parathyroids is made possible by a secretion from the anterior lobe of the pituitary gland.

The Intermediate Lobe

This portion of the pituitary gland produces a hormone known as *intermedin*, which has been found in all vertebrates so far studied. The effects of this hormone may be readily demonstrated in frogs and other amphibians. At the present time its function in mammals is not known.

The Posterior Lobe

The posterior lobe of the pituitary gland consists of contributions by the *pars nervosa* and the *pars intermedia*. It is possible, therefore, that its products may contain secretions from both sources. Two fractions have been isolated from the posterior lobe, called respectively *pitressin* and *pitocin*. However, much work on these hormones still remains to be done before the various effects noted on the cardiovascular, respiratory, uterine, renal organs, and the smooth muscle-tissue of the intestine and mammary glands are proved to be due to one or to several discrete fractions. Several characteristic reactions, however, might be noted. First there is the *pressor effect* which is characterized by an increased blood pressure and a decreased heart-rate. Injections of the posterior lobe cause an increased secretion of urine and also bring about a contraction of the plain muscle of the uterus. This latter action has been made use of by the medical profession to stimulate the contractions of the uterus at childbirth. If an animal is lactating, injections of the posterior lobe will bring on an increased flow of milk.

From this brief account may be gathered some idea of the way in which this small endocrine gland functions as the commander-in-chief of the metabolism of the body. Although much work remains to be

done in this connection, it is nevertheless apparent that the pituitary gland exercises an interlocking directorate over the remaining lesser lights of the endocrine constellation.

SUGGESTED READINGS

Clendinning, L., *The Human Body*, Alfred A. Knopf, Inc., 1930. Ch. IX.

Interestingly written account of the problem of co-ordination.

Cobb, I. G., *The Organs of Internal Secretion*, 4th ed., Wm. Wood and Co., 1933.

Fairly technical discussion of functioning and non-functioning of endocrine glands.

Rogers, C. G., *Textbook of Comparative Physiology*, McGraw-Hill Book Co., 1927. Ch. XXV.

Discussion of the endocrines and their work from a comparative viewpoint.

THE MAINTENANCE OF SPECIES

XIX

REPRODUCTION AND LIFE CYCLES

PREVIEW. Where did life come from? : Refutation of spontaneous generation; other theories of the origin of life; life produces life · Regeneration · Asexual types of reproduction: Budding; fission · Sexual reproduction in the invertebrates: protozoa; other invertebrates; hermaphroditism · Parthenogenesis · Paedogenesis · Alternation of generations · Sexual reproduction and development in the vertebrates: Germ cells versus soma cells; fertilization, results of fertilization; early cleavage and variations caused by yolk; blastulation; gastrulation; mesoderm formation; early differentiation of the embryo · Tissue formation · Protective devices for the embryo: Egg shells; the yolk sac; amnion and chorion; allantois; placenta · Elaboration of germ cells or gametogenesis: Formation of sperm — spermatogenesis; formation of ova — oögenesis · The new embryology: Genes; environment; natural potencies; organizers · Suggested readings.

PREVIEW

It was obvious to the early philosophers that the earth preceded the living things upon it and they advanced the interesting idea that living things arose spontaneously from their surroundings. The Bible alludes to this belief when Samson propounded his riddle, "Out of the eater came forth meat and out of the strong came forth sweetness." Samson saw flies coming out of the decaying body of a lion, took the flies for bees, which he believed were arising spontaneously from the lion's body, hence the riddle. The story of the long struggle to disprove spontaneous generation, ending with the conclusive demonstrations of Louis Pasteur, makes one of the fascinating bits of reading in the field of biology.

With the disproof of the existence of spontaneous generation and the perfection of the microscope, great interest was evidenced in the many different ways in which plants and animals reproduced. Today the student of embryology sees the apparently many diverse ways of reproducing the species reduced to a few essentially similar fundamental patterns.

Likewise the exactness with which the chromatin is segregated and divided within the developing germ cell is a never-ending source of

wonder to the biologist. Another interesting study centers about the development of the various protective devices that surround the embryo and keep it from injury until it is hatched or born. The infinite care with which these devices have been developed is a credit to the ingenuity of Mother Nature.

In this unit the student will find the answer to questions arising in his mind concerning the nature of these reproductive devices.

Where Did Life Come From?

Greek and Roman literature is full of references to the possible origin of life and to the probability that it arose spontaneously. A few brave souls dared to doubt this almost universally accepted concept. However, even as late as the 17th century Alexander Ross writes,

"So may we doubt whether in cheese and timber worms are generated, or if beetles and wasps in cow-dung, or if butterflies, locusts, shellfish, snails, eels, and such life be procreated of putrefied matter, which is to receive the form of that creature to which it is by formative power disposed. To question this is to question reason, sense, and experience. If he doubts this, let him go to Egypt, and there he will find the fields swarming with mice begot of the mud of Nylus, to the great calamity of the inhabitants."

Refutation of Spontaneous Generation

Belief in spontaneous generation was first shaken by the Italian physician Redi, who noticed that flies were attracted to decaying meat. In an experiment he put sterilized meat into several jars, covered one lot with parchment, another lot with a fine netting, and the third he left open. Fly maggots were found later in the meat in the open jars, fly eggs on the netting, and no maggots in the parchment-covered jars. This experiment should have exploded the belief that maggots arose spontaneously from rotting meat. However, the belief kept constantly recurring because it was very difficult to prevent the invasion of food materials by bacteria, even after the substances and vessels containing them were apparently sterilized. The Abbé Needham, seventy years after the Redi demonstration, experimented with living germs, and because of the errors arising from improper sterilization found living germs in flasks of nutritive fluid that had first been heated and then were sealed with a resinous cement. A little later the Italian, Spallanzani (1729-1799), placed nutrient fluids, such as meat and vegetable juices, in glass flasks, the necks of which were sealed in a flame; then he placed the flasks in

boiling water for three quarters of an hour. The contents of the flasks remained unchanged. Spallanzani then opened the flasks and after a short period they were found to be full of living organisms. Needham objected to the experiments on the ground that the boiling had killed the "vegetative force" of the infusion. However, the idea of spontaneous generation was not finally disproved until the time of Pasteur and Tyndall, who proved that living germs may be carried about by dust in the air and that only when air containing dust particles can be excluded from substances it is certain that bacteria will not grow in them.

Other Theories of the Origin of Life

The theory of the simultaneous creation of life and this planet does not agree with such theories as the scientists offer to account for the origin of the earth. Whether we accept the nebular hypothesis of LaPlace, the later planetesimal hypothesis of Chamberlin, or the still later theories of Green or Shapley, we are confronted in all of them by the formation of our planet from material far too hot to sustain life. As Jeans says, "The physical condition under which life is feasible is only a tiny fraction of the range of physical conditions which prevail in the universe as a whole." The theory sometimes advanced that life may have been transferred from another planet does not help us much, for we still have to account for life's origin. As has been so well said of life on Mars, which of any of our planetary neighbors has conditions the most possible for supporting life, "Man reconstructed to walk on Mars would be crushed to death by his own weight on the earth." Special creation as advocated by the early Church does not help the scientist very much, for it still leaves life to be accounted for. It allows of no scientific investigation and so it cannot be used by the biologist.

Probably the theory which has the most hope of ultimate solution is the belief that at some time life arose by a chance combination of chemical elements of which the earth is made. Evidence found in the rocks indicates that the earth is much older than its inhabitants. Professor Henry F. Osborn pointed out the striking similarity of the salts found in the blood and those found in sea water. He made the suggestion that life might have originated in some pool in which the saline contents contained the life elements found in protoplasm. Would it be too much to speculate on the origin of some simple form of life by allowing a flash of lightning to release the pure nitrogen

of the air in some form of nitrate which would combine with the life elements found in sea water and the carbon dioxide of the air? This theory is in reality a refurbished concept of spontaneous generation. In discussing it two points should be kept in mind. First, *if* spontaneous generation of this sort *did* occur at one time, the contrast between the physical environments of the past and present would be great. Second, even if conditions were right for the similar production of life today, it appears likely that such simple beginnings would be almost immediately destroyed by better established forms of life. Both serve as explanations of why we do not have life produced spontaneously today.

Life Produces Life

Since the time of William Harvey, court physician of Charles I of England, the statement "*Omne vivum ex ovo*" has been used. Living things come from other living things, not always from eggs, as Harvey said, but in the case of unicellular animals and plants by the cell dividing to form two.

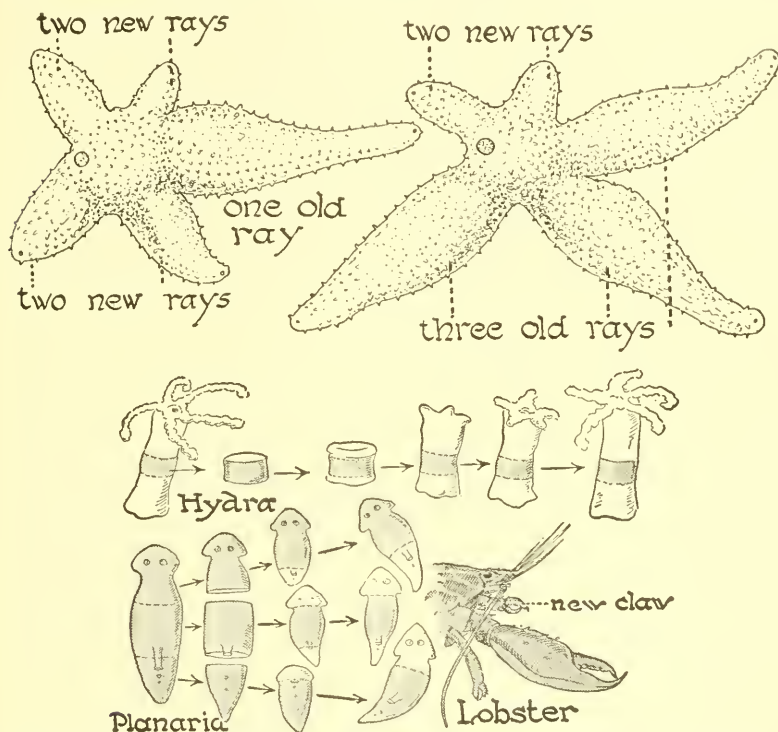
Each organism, plant or animal, has a definite life cycle, a series of changes which it goes through from its simplest form as an egg to its ultimate adult structure. More than this, sooner or later it will die. In some unicellular forms the life cycle takes a very brief period indeed, but in the elephant it is over a hundred years, and some trees, like the giant sequoias, live thousands of years. Sooner or later life activities cease and the Biblical statement of "dust to dust" is justified. Death comes as a final close of all activity and normally after the animal or plant has produced offspring.

New individuals, whether complicated mammals or simple protozoans, arise from the same kind of pre-existing organisms. The exact method of reproduction, however, varies markedly in different groups. Protozoa, at one end of the scale, produce new individuals by the simple process of cell division, while the mammals, at the other extreme, show evidence of considerable division of labor with special organs involved in the production and functioning of the highly specialized sex cells. In order to understand these various processes it is desirable to summarize the different reproductive devices which appear in the animal kingdom.

Regeneration

The replacement by an organism of lost or injured tissue is included in this discussion of reproduction on the ground that such a phe-

nomenon, involving the creation of new cells by cell division, is a fundamental type of growth. The ability to regenerate lost parts seems to be correlated inversely with the degree of specialization and the extent to which division of labor appears. For example, an unspecialized sponge when pressed through silk bolting-cloth into small fragments will reproduce new individuals. Other more highly



Examples of regeneration in representatives of four different phyla. How may such phenomena be explained?

specialized forms show less ability to regenerate so completely, but many of the coelenterates as well as certain worms and echinoderms possess this facility of regeneration to a high degree. Starfish, long the enemy of oysters, have increased rapidly in part due to the careless practice of oystermen who tore them apart and left the fragments in the water. It is now known that such disjointed parts, if containing portions of the central disk, are capable of regenerating into new individuals.

Lobsters, crabs, spiders, and some insects have the uncanny ability of breaking off an injured appendage near its base, a phenomenon known as *autotomy*. In such instances new appendages are usually regenerated and the animal emerges as a successful contestant in another skirmish in the struggle for existence. Vertebrates, however, show but slight ability to replace lost parts. Of course a break in the skin is soon healed by regeneration, although more extensive damage to the part results merely in the elaboration of some connective tissue and skin and not in complete restoration. A crushed toe, for example, usually necessitates an amputation, for in such cases one never finds a new toe replacing the old.

It is a rather striking fact that the more limited type of regeneration common among the higher vertebrates is almost indistinguishable from the normal metabolic processes so characteristic of growth and repair. It is only a step from such methods of growth to the highly specialized type known as *reproduction*.

Asexual Types of Reproduction

Budding and fission, or simple cell division, comprise the usual asexual methods of reproduction. A brief consideration of these methods at this point will serve to link regenerative processes with those of higher types of reproduction. The former may be thought of as reproduction by an unequal cell division, a mode of division not infrequently found among one-celled organisms. In more complex organisms, as *Hydra*, repeated divisions of totipotent cells may occur to produce a bud. Fission merely involves the division of an organism into two or more, usually approximately equal parts.

Budding

Organisms which undergo budding might easily be confused with those exhibiting regeneration. These phenomena closely resemble each other, the chief difference being that budding, unlike regeneration, does not typically result from injury. It is, moreover, an important type of reproduction occurring quite generally in plants as well as widely throughout the lower animal kingdom.

The fresh-water sponge reproduces by means of two kinds of buds, the first type being liberated to take up a separate existence while the second remains as a kind of internal bud, called a *gemmule*. It

has been previously shown that in *Hydra* the new bud extends out from the body, developing tentacles, mouth, and hypostome at the distal end of the organism. After growing sufficiently the base constricts and the two animals, parent and offspring, become separated, each taking up an independent existence (page 184).

In the higher worms such as the palolo worm and the Naididae, a type of budding occurs which might be described as *fragmentation*. The number of fragments apparently depends upon the size of the worm, each piece usually producing all of the missing parts.

Fission

This variety of asexual reproduction is the most common. The one-celled protozoa rely almost exclusively upon this type of development, seldom resorting to the more complicated "sexual" methods. In *binary fission* the nucleus appears to take the initiative, since it divides first and is followed by the division of the cytoplasm of the cell.

Fission is rather closely allied to budding. Many of the turbellarian and nemertinean flatworms utilize this method, as, for example, the turbellarian, *Microsiomum*, which often divides into two, four, or even sixteen pieces. These parts produce all of the necessary structures except eye-spots and often remain attached in chains for long periods of time.

Sexual Reproduction in the Invertebrates

Protozoa

Sexual reproduction involves the union of two cells produced usually by two animals of different sexes. This phenomenon appears in practically every group of the animal kingdom. Even in the protozoa there are two types of reproduction which may be thought of as initiating the sexual method. In the first type there is either a complete union of two individual cells of equal or of unequal size, or there may be specialized cells called *gametes*. Many variations of this type are to be found among different species.

The second type of sexual reproduction occurring in the protozoa is called *conjugation*, which has already been described (page 161). Briefly, conjugation means that two single-celled organisms come together temporarily, form some sort of protoplasmic bridge, exchange

nuclear material, and finally separate. If the conjugating forms are of equal size, as in the case of *Paramecium*, both usually survive and continue to reproduce, by asexual means. On the other hand, when the conjugants are of unequal size it frequently happens that the smaller, or *micro-conjugant*, degenerates soon after conjugation.

Other Invertebrates

As division of labor among the cells of an organism progresses there is increasing evidence of a gradual but none the less clear demarcation into two sorts of cells, the *soma* or body cells, and the *germ* or sex cells. These groups are separated early in the development of the individual, the former being burdened with the responsibilities of movement, protection, securing food, and in some cases caring for the young. The second, comprising the germ cells, is solely concerned with the elaboration of highly specialized cells adapted for the production of new individuals, and so serving for the maintenance of the race.

Since sexual reproduction undergoes many modifications in the invertebrates, it appears logical to consider some of these phenomena before undertaking a detailed study of sexual reproduction in the higher vertebrates.

Hermaphroditism

Many of the lower invertebrates exhibit a kind of sexual reproduction in which both the male and female organs are found in the same individual. A complete set of male and female reproductive organs occurs, for example, in a single *Hydra*. In this genus the *spermary* producing the spermatozoa is situated closer to the tentacular region than the *ovary* which is located near the foot. These gonads rupture when mature, and one of the liberated spermatozoa finally fertilizes the ovum contained in a disrupted ovary. When both gonads are functional on the same individual *self-fertilization* may occur.

The earthworm likewise contains a complete set of male and female reproductive organs in the same individual, but here, as in many of the trematode flatworms, copulation takes place between two separate individuals. In such cases the exchange of spermatozoa results in *cross-fertilization*.

While hermaphroditism is unusual in the vertebrates, it is believed to occur normally in a few instances such as certain hagfishes (cyclostomes) which are known to be hermaphroditic. In these forms,

however, cross-fertilization occurs, since the ova and spermatozoa mature at different times. Reported cases of functional hermaphroditism among mammals appear to be highly doubtful.

Parthenogenesis

The development of an egg without fertilization by a sperm occurs quite commonly under natural conditions in some invertebrate forms. Usually there is a cessation of activity on the part of the males for a period of time when ova, produced by the females, develop into apparently normal individuals. In some few instances males are permanently absent. The rotifers, water fleas (*Cladocera*), and plant lice (aphids) all exhibit this type of development at times. In cladocera, of which *Daphnia* is a well-known example, the females produce parthenogenetic eggs during the warm weather. From two to twenty eggs, depending upon the species, are deposited and nourished in the brood-sac. Usually several generations of females will be produced in this fashion. Eventually male as well as female daphnids are produced, and the eggs from this generation of females must be fertilized by the males. When fertilization occurs, the eggs are covered by the highly resistant protective portion of the brood-sac (*ephippium*) which enables them to withstand desiccation and the rigors of winter.

Numerous experimenters have been interested in attempts to induce artificial parthenogenesis in various invertebrate eggs by means of chemical or physical stimuli ranging all the way from simple salts and complex fatty acids to mechanical means, such as pricking with a needle, shaking, or raising the temperature of the water surrounding the experimental organisms. Mead first successfully induced artificial parthenogenesis with the ova of annelids and Loeb extended the experiments to include starfishes, sea urchins, molluses, and even frogs, which underwent at least partial development by means of various chemical or physical stimuli aptly described as *parthenogenetic agents*.

Most of the experimental efforts to induce parthenogenesis in vertebrates have been rewarded by failure. In a few instances tadpoles have been produced through mechanically initiating cleavage of the egg by pricking with a needle and introducing a small amount of blood serum at the same time. Pincus has also been able to carry a mammal embryo through early developmental stages after parthenogenetic stimulation.

Paedogenesis

Reproduction by immature individuals is called *paedogenesis*. As it is rarely encountered in the animal kingdom, only two examples need be mentioned. The first occurs in the trematodes, where immature larval forms, such as *sporocytes* and *rediae*, appear to produce the next generation parthenogenetically. These in turn often give rise to another generation through paedogenetic reproduction. In the vertebrates the best known example is the Mexican axolotl, a urodelous amphibian. This interesting animal, while still remaining in its larval form, reproduces its kind sexually without undergoing metamorphosis or losing its external gills.

Alternation of Generations

Alternation of a sexual with an asexual generation is called *metagenesis*, or simply *alternation of generations*. Several of the invertebrates, especially the coelenterates, normally exhibit metagenesis. In the hydroid *Obelia*, for example, the asexual generation is represented by a sessile, colonial hydroid and the sexual generation by the mature, bisexual medusa buds (see page 185).

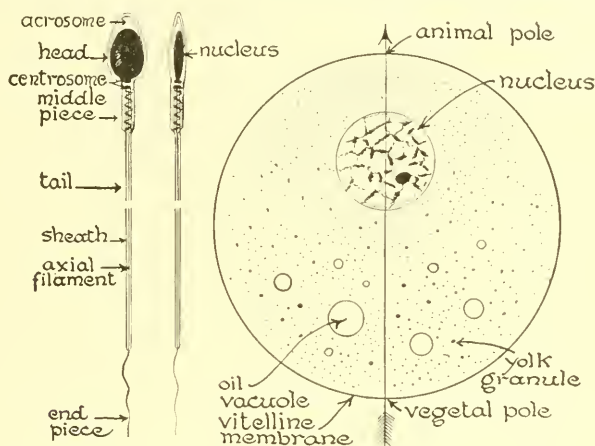
Sexual Reproduction and Development in the Vertebrates

Germ Cells versus Soma Cells

The early growth and later development of the embryo and its systems, *organogeny*, are to be considered in some detail. To complete the picture it is necessary to envision the continued growth of the organism until it matures, reproduces its kind, and dies. The life of every organism, whether plant or animal, is involved with the mathematical concepts of division, multiplication, addition, and subtraction. In the formation of a new individual by two parents, two germ cells are *added* together (*fertilization*). In order that the hereditary genes thus united may not be disastrously doubled in each generation, one half of those present from each contributing parent are *subtracted* by the elimination of either the maternal or the paternal member of each chromosome pair just prior to maturation. Thus, a constant number of chromosomes with their respective genes is maintained in each body cell of any species. After this preliminary process of subtraction and addition has been accomplished, the newly combined germinal cell, that is, the fertilized egg, or ovule, initiates

an exhaustive series of *divisions*, whereby each cell repeatedly becomes two (*growth*). The result of these successive divisions is an enormous *multiplication* of differentiating cells to form the entire body of the individual (*development*).

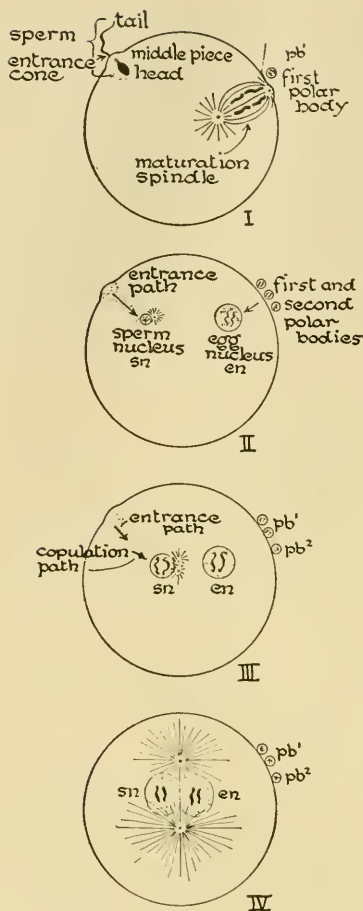
In the present connection it is only desirable to emphasize that this complicated process of cell-division (*mitosis*) has been exhaustively studied, so that its essentials are now well known. In a word, the end result is the final distribution, to every one of the innumerable cells that form the individual, of equal germinal contributions from the two parents in the form of gene-bearing chromosomes.



Generalized diagram of spermatozoan (left) and ovum (right) ready for fertilization. Note the two views of the spermatozoan. The head contains much nuclear material plus the acrosome. The middle piece contains two disk-like centrosomes, twisted *mitochondria* and cytoplasm, while the tail has an outer sheath and axial filament. Eggs are always larger than spermatozoa and contain varying amounts of reserve food. Yolk settles toward the vegetal pole. (After McEwen.)

Sexual reproduction in the vertebrates is essentially identical regardless of the group considered. In every case there is a special organ in the male called a *testis*, or spermary, for the production of sperm, and an *ovary* in the female in which eggs are elaborated. Each sperm or ovum is a single cell. Both kinds of germ cells differ in shape and size throughout the vertebrate series.

The tadpole-shaped spermatozoa are always much smaller, quite active, and lack nutrient material within their bodies, as contrasted with the sedentary ova in which food is stored for the prospective embryo. Sperm may be divided morphologically into three parts,



Generalized diagram of fertilization. (I) shows the formation of the first polar body, the maturation spindle of the second maturation division (see p. 429), and the penetration of the spermatozoan. The second polar body is formed by the second maturation division and the egg nucleus starts towards the center of the egg. The sperm nucleus, or male pronucleus, starts towards the center (II) *via* the entrance path, but turns (III) toward the center on its copulation path to meet the egg nucleus and be arranged on the equatorial plate (IV) for the first cleavage division. Note that the centrosomes for this division are supplied by the male pronucleus. (After McEwen.)

the *head*, *middle*, and *tail pieces*. The head is composed chiefly of chromatin and is usually more or less pointed. The middle piece constitutes the general region immediately posterior to the head and contains *cytoplasm*, *mitochondria*, *centrioles*, and the *axial filament*, while the *tail piece* appears to be primarily a locomotor device.

Ova, on the other hand, are always non-motile and much larger than the sperm, due primarily to the fact that ova contain nutritive material, or yolk, which is utilized *after* fertilization. The amount of yolk present in eggs of the various classes of vertebrates differs widely. In all forms in which the eggs develop outside of the body, as, for example, the fish, amphibians, reptiles, and birds, there must be enough nutritive material present in the form of yolk to supply the embryo until it hatches and can feed itself.

Fertilization

Fertilization consists of the union of a sperm and an ovum. This fusion may occur either outside of the body of the female, as in the case of most of the teleost fishes and other water-inhabiting animals, or within the oviduct of the female. Literally millions of sperm are liberated, but usually only a single sperm enters an

egg and in any event only one normally effects fertilization. The head and middle pieces usually become separated from the tail piece as penetration is effected, leaving the tail at the periphery of the ovum in much the same way that sandals are left at the portal of a Japanese house. The continued penetration of the remainder of the sperm is made possible through movements of the cytoplasm within the egg. The male element, which is now known as the *male pronucleus*, absorbs water, enlarges, and finally becomes arranged on the equatorial plate with the *female pronucleus* of the ovum, and the initial cell division follows.

RESULTS OF FERTILIZATION. The more important effects of fertilization may be briefly summarized as follows: (1) *Reproduction*. This is accomplished by restoring the normal (diploid) number of chromosomes and by so doing producing a new center of cell division. (2) *Variation*. As will be seen later, the whole phenomenon of maturation of the germ cells and the consequent reduction of chromosomes to the haploid number makes possible new combinations and variations between fertilized ova, or *zygotes*, upon which natural selection may act. (3) *Rejuvenescence*. For years fertilization and the concomitant stimulation of protoplasm have been thought necessary to revivify an organism. Data have been collected both in support of and in contradiction to this theory. Endomixis, as shown by Woodruff (page 161), apparently acts as the rejuvenating agent in nonconjugating strains of protozoa.

Early Cleavage and Variations Caused by Yolk

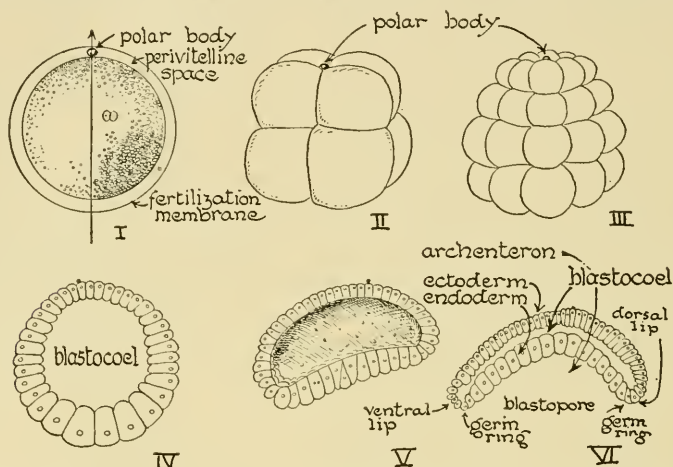
Once fertilization has occurred, cell division proceeds rapidly and the zygote gives way to the early cleavage stages. In the simplest types each plane of cleavage typically passes at right angles to the preceding plane, the cells multiplying from the two-celled to the four-celled stage, and so on up until the number in a given cleavage stage cannot easily be determined.

The amount of yolk present in the egg affects the cleavage rate and even the pattern of development, since yolk is denser than typical cytoplasm and, therefore, settles toward the lower side of the egg. Its presence affects the rate of cell division by slowing it down. If yolk is present in large amounts as in bird and reptile eggs, it tends to occupy most of the available space in the ovum. In such ova the embryo develops in the upper polar area, or in a restricted disk called the *blastoderm* lying on top of the yolk mass. The ova of

amphioxus and of mammals contain but a small amount of equally distributed nutritive material, while a third type of distribution occurs in some insect eggs where the yolk is concentrated in the center of the ovum.

Blastulation

In *isolecithal* eggs, in which the yolk is distributed throughout the egg, the cells produced by successive divisions are all of approximately the same size, and cleavage progresses with regularity until



Cleavage in *Amphioxus*. Note fertilization membrane (I) and decrease in cell size as blastulation occurs (II-IV). Gastrulation (V, VI) follows with a reduction of blastocoel and formation of gut (*archenteron*). (After Conklin.)

the embryo is a mass of increasingly smaller undifferentiated cells. A central cavity is produced as soon as the scanty yolk is used up to furnish fuel for cell division. As a result the entire mass resembles a rubber ball with the surface representing the layer of outside cells and the cavity inside of the ball forming the *blastocoel*. This stage is called a *blastula*, and the process whereby it is formed is known as *blastulation*.

Gastrulation

As mitosis continues after blastulation, the cells on the side containing the yolk gradually become larger and eventually are pushed inward much as one would push in the side of a hollow rubber ball with the finger. The new cavity thus formed represents the primitive gut, or *archenteron*, and the embryo is now spoken of as a *gastrula*.

Thus far two germ layers can be differentiated, an outer layer of *ectoderm* and an inner one of *endoderm* which lines the archenteron, while the diminishing remains of the blastocoel lie between. This stage is suggestive of those organisms, like the coelenterates, which characteristically possess only two germ layers even in the adult condition, and are therefore designated as *diploblastic*.

Mesoderm Formation

The details of the further development of the embryo vary considerably, depending upon the form studied, but all of the higher forms above the coelenterates produce a third germ layer called the *mesoderm*. The elaboration of mesodermal tissue may come from either, or possibly both, of the primary germ layers. In all of the vertebrates, two sheets of mesodermal cells are formed, an inner *splanchnic layer* associated with the inner tube, or developing gut, and an outer *somatic layer*, which is contiguous with the ectoderm. Loosely scattered mesodermal cells (*mesenchyme cells*), derived from these more compact layers, fill in the narrow spaces between the gut and splanchnic layer and between the somatic layer and ectoderm.

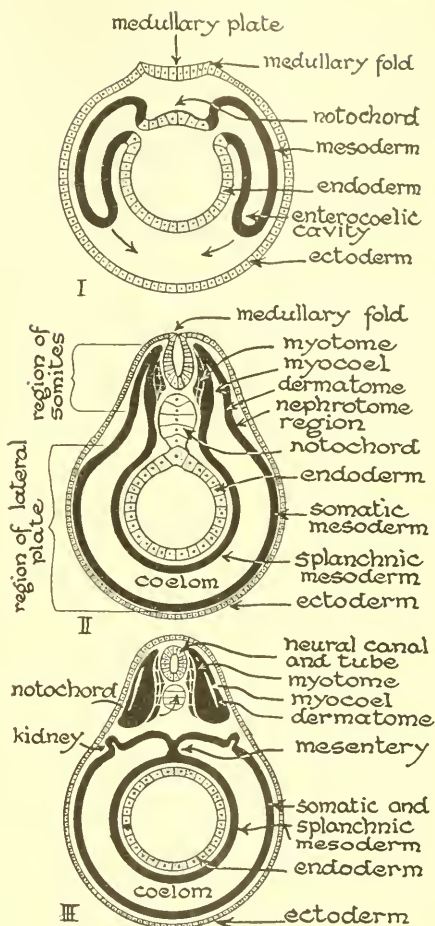


Diagram of a generalized vertebrate to show the origin and early differentiation of the ectoderm, endoderm, and mesoderm. (I) shows the mesoderm arising by means of the enterocoelic pouches budding off from the archenteron. Above and between these pouches lie the beginnings of the notochord. In (II) the medullary plate has formed the neural tube and the mesoderm has become differentiated into regions which will form somites (myotomes), kidneys, and linings of the body cavity. This differentiation goes still further in (III). (After McEwen.)

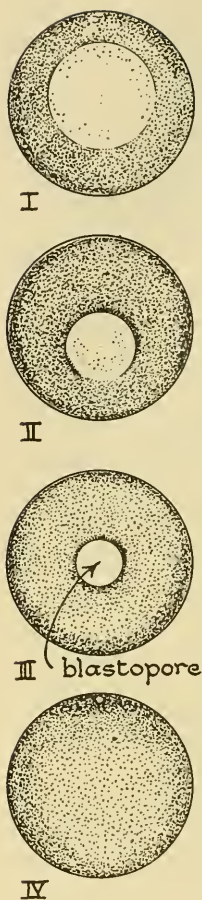
Early Differentiation of the Embryo

Diagram to show the closure of the blastopore in a frog. Figures I to III are views from the vegetal pole. The rotation so typical of developing amphibian eggs has been started in III and completed in IV. The view in IV is from the potential ventral side of the embryo. (After Jenkinson.)

It must be borne in mind that the changes outlined follow a definite pattern and that some of them are going on simultaneously. One of the first changes after gastrulation is a gradual increase in the length of the embryo due largely to the rapid cell divisions about the lips of the *blastopore*, which forms the exterior opening of the archenteric cavity. The result is a gradual fusion by a backward growth of the lips of the blastopore, which thus produces an elongated line, the *primitive streak*. This is one of the best known embryological landmarks. Anterior to the primitive streak there soon develops, partially produced by a sinking of the ectoderm, two closely associated parallel folds of ectoderm, which extend anteriorly forming the walls of the *neural groove*. Gradually an anterior-posterior fusion of the walls of the groove produces the *central nervous system*, a dorsal tubular structure characteristic of the vertebrates. Sheets of mesoderm likewise grow anteriorly and laterally from the region of the primitive streak, soon splitting distally to form the splanchnic and the somatic layers. Meantime beneath this the gut is forming and being pinched off from the yolk beneath. In its anterior part, the pharyngeal gill-pouches and later the gill-slits appear, together with out-growths which form the lining of the thyroid and thymus glands. Posterior to this region there soon develops a ventral out-pocketing of the gut, which later forms the lungs in land animals, while still further posteriad lie the forerunners of the liver and pancreas.

The degree of closure of the gut along the ventral surface of the embryo is largely dependent upon the quantity of yolk present in the egg. An egg containing little or a moderate amount of yolk, as in *Amphioxus* or the frog, respectively,

has the ventral body wall completed early in development. In such forms the yolk that remains is carried within the body of the embryo and is accessible as fuel for further metabolism.

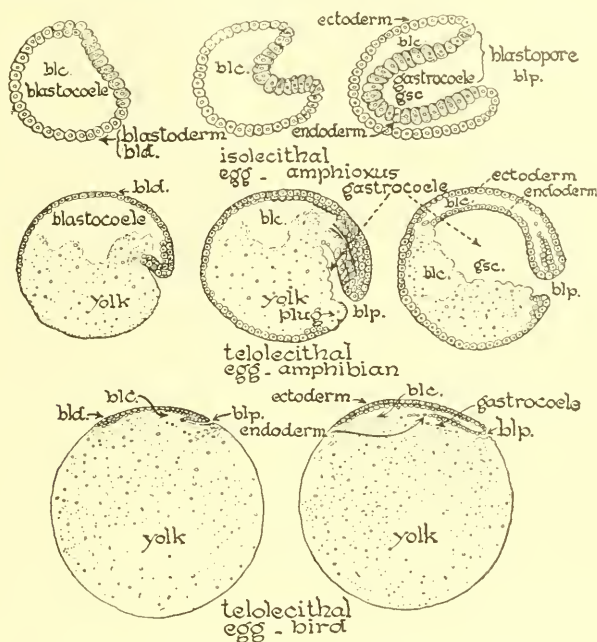


Diagram showing effect of yolk on the formation of the gastrula. Read text p. 420 and attempt to describe the effect of yolk on gastrulation. (After Patten.)

In many of the fishes that are relatively large-yolked forms, development is similar. Young fry of the small-mouthed bass carry around enough yolk to maintain their "flame of life" for about two weeks, after which they begin feeding on the usually plentiful plankton organisms. Whereas in a *macrolecithal* type with an abundant supply of yolk, such as a bird's egg, the gut fails to close until a much later date, the embryo literally floating on top of the mass of potential food. Even as development continues there is such a vast quantity of yolk present that it appears impossible for the embryo to complete the ventral body wall until much of the potential food material has been absorbed. As this process takes some time the embryo remains independent of other sources of food material until it gradually depletes the supply, and surrounds the remainder of the yolk with the continued outgrowth of the gradually extending germ layers.

Tissue Formation

Each of the three primary germ layers produces a number of different tissues that in turn form the various organ systems. Briefly summarized, the *ectoderm* forms all of the nervous tissue, which in turn makes up the nervous system, as well as the organs of special sense that are developed in connection with it. The ectoderm also gives rise to the epidermis of the integument and its various derivatives such as scales, hair, horn, nails, feathers, and the enamel of the teeth. In addition the linings of the mouth, anus, and nasal passages also come from the ectodermal epithelial tissue.

The *endoderm* forms the epithelial tissue lining the digestive tract with the exception of its extremities which come from the ectoderm. Many zoologists believe that all the various outgrowths from the digestive tract, for example, the lungs, air tubes, and liver, as well as various out-pocketings from the pharynx such as the thymus and thyroid, contain a significant endodermal contribution. In some chordates, the notochord buds off from the endoderm. It should be noted, however, that in the case of the lungs and liver considerable amounts of mesodermal tissue also enter into the formation of these organs.

The *mesoderm* is the largest contributor to the tissues and different systems of the body. The circulatory tissue is derived from the mesenchyme of the mesoderm, while both skeletal and muscular tissues and frequently the notochord come from this germ layer. Likewise, both the excretory and reproductive systems are derived from the mesoderm, which also makes some contribution to the respiratory system. Finally the derma of the skin, cartilage, connective tissues, such as ligaments and tendons, and the peritoneal lining of the coelomic cavity, may be classified as mesodermal derivatives.

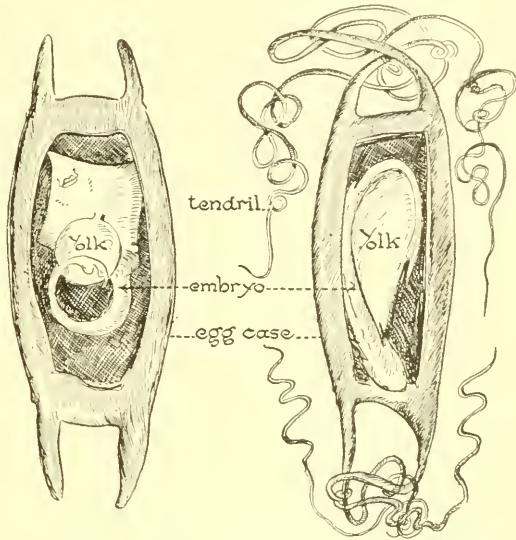
Protective Devices for the Embryo

Egg Shells

Various and sundry varieties of protective envelopes for ova are found throughout the animal kingdom. Although protozoa do not have eggs, encysted forms are protected from unfavorable environmental conditions by hard coats analogous to shells. For example, the cyst of *Endameba histolytica*, the causative organism of amebic

dysentery, passes from the alimentary canal of man safely protected by a thick, hyaline coat, until such time as ingestion by a suitable host brings about its dissolution in the host's stomach. The eggs of some of the tapeworms and roundworms are surrounded by dense impervious shells, rendering them viable, in the case of *Ascaris*, for five or six years. Some of the parasitic roundworms are ovoviviparous, retaining the eggs within the body of the parent until they are nearly ready to hatch.

A few fishes, like some of the skates, produce an egg surrounded by a hard, leatherlike case, which is drawn out into entangling tendrils that readily become enmeshed in seaweeds, thus affording protection to the egg. Most of the fresh-water fishes and amphibians, however, lay eggs which are protected by nothing more than a gelatinous mass which swells after the eggs are laid in the water and are fertilized



Embryo and egg case of skate. Such cases afford protection against wave action. What other types of adaptations are there for the protection of eggs and embryos? (After Walker.)

by the sperm. Among the reptiles and birds a hard shell is usually produced which gives protection to the enclosed ovum with its stored food. Only one small group of mammals, the monotremes, lay eggs, all others being viviparous.

The Yolk Sac

Among the fishes which lay *telolecithal* eggs containing enough yolk to render the cleavage pattern irregular, a mass of undivided yolk accumulates beneath the developing embryo. Soon, however, the blastoderm upon which the embryo lies grows down over the yolk, eventually enclosing it. This mass of tissue is composed of an inner layer of endoderm and an outer lining of mesoderm and is called

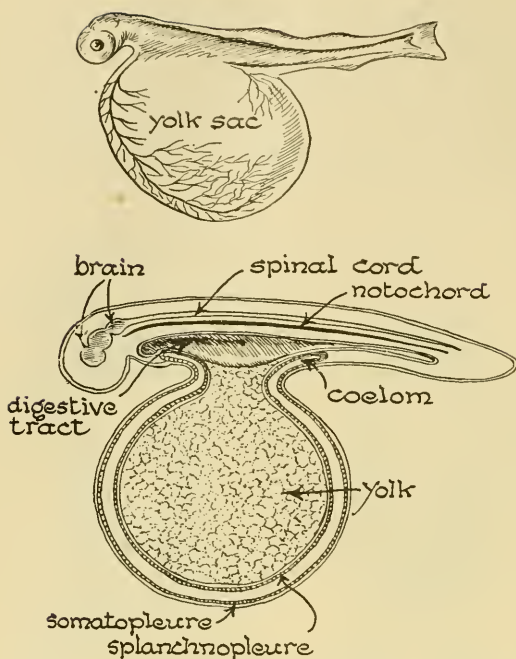


Diagram of a developing fish embryo. Note the "contained" yolk sac. What is its ultimate fate?

the *yolk sac*. Gradually blood vessels develop in the mesenchyme of the yolk sac, facilitating the transportation of food to the developing embryo.

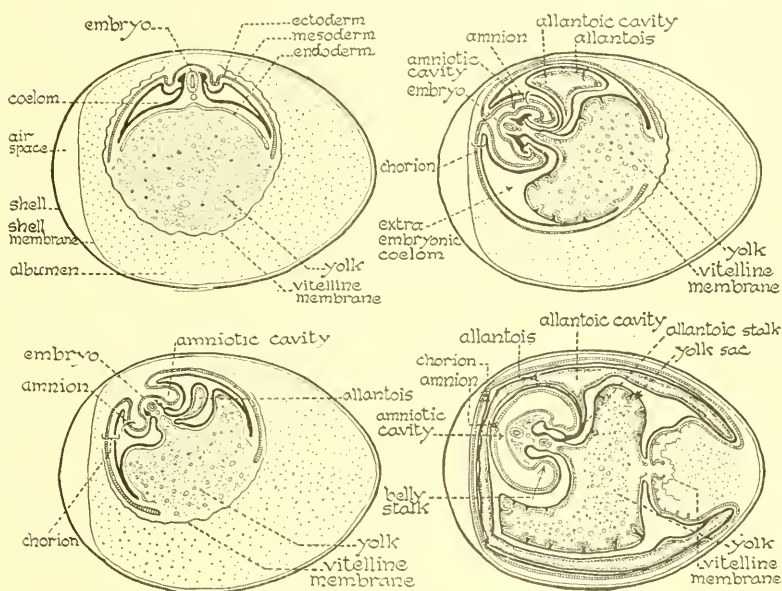
Amnion and Chorion

In addition to the protection afforded by egg membranes or shells and the yolk sac, the higher vertebrates, namely, the reptiles, birds, and mammals, elaborate additional *embryonic membranes* that serve not only as supplementary protective devices to keep the embryos from mechanical injury but also temporarily

handle the problems of respiration, excretion, and nutrition. In order to understand their functions, and the fact that their evolution is intimately tied up with that of the land-inhabiting reptiles, birds, and mammals, one must trace their embryological development.

As long as organisms returned to the water during the breeding season, as the amphibians still do, the exchange of gases and elimination of wastes takes place directly, since the surrounding water not only contains sufficient dissolved oxygen but also it soon dissipates waste products which are passed through the egg membranes and eliminated. With the acquisition of a land habitat, the inability to return to the water to spawn presented new problems, centering about the control of metabolism in the embryo. These needs were met through the elaboration of a series of embryonic membranes, which were apparently developed to facilitate the carrying on of normal metabolic processes through a permeable egg shell. They occur in modified forms in all land vertebrates.

The first of these new membranes to be considered are the *amnion* and *chorion*. They may be best understood by studying their origin. It will be recalled that in telolecithal eggs the endoderm does not succeed at once in growing ventrally to meet, and so to close, the digestive tube. Instead the unclosed tube lies flat upon the surface of the yolk. Both the ectoderm and mesoderm grow laterally over the endoderm directly over the yolk on the inner layer of the blastoderm. The mesoderm as a whole divides into three portions, the



Development of the extra-embryonic membranes in the chick. State the contribution of each germ layer to the amnion, chorion, and yolk sac. (After Patten.)

first of which is the upper *epimere* part immediately flanking the developing neural tube and producing the *somites*. Beneath the *epimere* lies a small *mesomeral* portion that later develops the excretory and reproductive systems from a ridge lying in the dorsal wall of the coelom. The mesoderm below the mesomere is the *hypomere*, which soon divides into an outer somatic and inner splanchnic layer of mesoderm. In large-yolked eggs this hypomeral portion extends laterally over the endoderm which is covering the surface of the yolk. In all of the higher groups, beginning with the reptiles, the

superficial ectoderm and the outer or somatic mesoderm are contiguous, and together are called the *somatopleure*. They grow up from the surface to produce folds known respectively as *head*, *tail*, and *lateral folds*, and these folds in turn grow up and over the embryo from the head posteriorly until they meet and fuse. Upon dissolution of the wall at the point where these folds meet, two new complete layers covering the embryo are produced, the inner layer of somatopleure being known as the *amnion*, and the outer as the *chorion*. The amniotic cavity between the amnion and the embryo is lined with ectoderm and becomes filled with a shock-absorbing *amniotic fluid* which serves the additional function of keeping the embryo moist. Outside the amnion is the *chorionic cavity* which is lined with somatic mesoderm.

All of the time that the head, tail, and lateral folds of the amnion are developing, the yolk is being reduced and the *splanchnopleure*, composed of the endoderm and splanchnic mesoderm, is growing down and around it to complete the yolk sac. The outer margins of the somatopleure at the base of the developing amniotic folds likewise continue to grow down and around the yolk sac until they finally meet ventrally. This new layer may really be called a continuation of the chorion, while the cavity lying between the outer surface of the yolk sac and the inner side of the chorion is in reality but a continuation of the *body*, or *coelomic cavity*. Because of its position this portion of the coelomic cavity becomes known as the *extra-embryonic coelom*. It will be seen from the figure (page 425) that the chorionic cavity is nothing but an outgrowth from this.

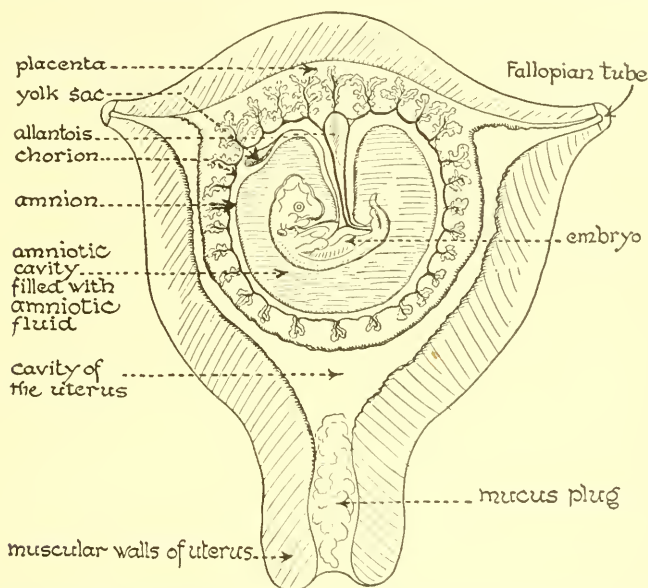
Allantois

A yolk sac is developed in all of the egg-laying types of reptiles and birds. Even in the mammals, it is present in a reduced form. Reptiles, birds, and mammals, however, develop a fourth embryonic structure called the *allantois*, which serves as an excretory and respiratory organ. While the yolk sac is attached by a *yolk-stalk* to the mid-gut region, the allantois develops as a diverticulum from the ventral surface of the hind-gut. Its growth does not start until after the amnion and chorion are in the process of formation. Almost at once, however, this out-pocketing encounters the inner layer of mesoderm so that the allantois comes to be lined by endoderm on the inside and covered by splanchnic mesoderm on the outside. The outgrowth continues, extending out into the extra-embryonic coelom and up

into the chorionic cavity. Thus the allantois in reptiles and birds comes to lie close to the porous shell, where it is well supplied with blood vessels and so readily becomes a membrane through which oxygen may be secured and the various waste products of metabolism eliminated.

Placenta

In all mammals except the egg-laying types and the marsupials, who bring forth their young in an immature stage of development, a new mechanism, the *placenta*, is evolved to supply the metabolic needs



Diagrammatic sagittal section of human uterus. What devices do you find for protection and nourishment?

of the embryo. Other important changes are associated with the formation of this structure. In the first place the developing embryo reaches the uterus and becomes implanted in the uterine mucosa at about the time of gastrulation. The amnion is formed and serves the same protective function as in the lower types, while the chorion is intimately associated with the maternal tissue lining the uterus and so becomes concerned with respiration, excretion, and nutrition. Blood vessels invade this modified chorion, extending from it down the

umbilical cord to the embryo. From the surface of the chorion fingerlike projections, or *villi*, push out which interdigitate with similar fingerlike processes of the uterine wall, thus facilitating the maintenance of metabolism. This portion of the chorion together with the wall of the uterus in which the embryo is embedded is usually designated as the *placenta*. While there is no exchange of blood between the parent and embryo, their two blood streams in the case of the primates are separated only by the lining of the fetal capillaries, the connective tissue surrounding them, and the epithelial layer on the surface of the chorionic villi. While the allantois does develop in the mammalian embryo, it is incorporated into the growing placenta and in primates is really functionless, except for the proximal portion which is transformed into the urinary bladder of mammals. As the embryonic membranes are not permanent structures they are discarded at birth.

Elaboration of Germ Cells, or Gametogenesis

It should be borne in mind that the germ cells themselves can be traced back in the developing embryo only to a certain point which varies in different groups. In the chick, for example, the germ cells may be traced to the anterior margin of the blastoderm. In some invertebrates, such as *Ascaris megalocephala bivalvens*, it has been shown that the germ cells may be detected at the thirty-two cell stage. In the latter instance the *primordial germ cell* may be readily detected by its size.

While the primordial germ cells are present early in the life of the individual, it frequently happens that the organism does not mature for some time and consequently the development, or *maturation*, of functional germ cells is delayed. Usually the maturation process covers a considerable period of time which, in the case of a male, terminates in the elaboration of sperm. Hence the entire process is called *spermatogenesis*, while in the female the production of ova is known as *oögenesis*. Both phenomena may be spoken of collectively as *gametogenesis*.

Formation of Sperm — Spermatogenesis

The primordial germ cells of the male undergo an extended period of division, the resulting cells of which are designated as *spermatogonia*. These reproduce other spermatogonial cells by normal

mitotic cell division, and when ready for the final maturing stages they first undergo a period of growth in which the cells increase somewhat in size. At this point one must look inside the cell to see what is happening within the nucleus. Here the chromosomes are paired. Each member coming from the male or from the female parent, respectively, is identical as to shape and size with the exception in

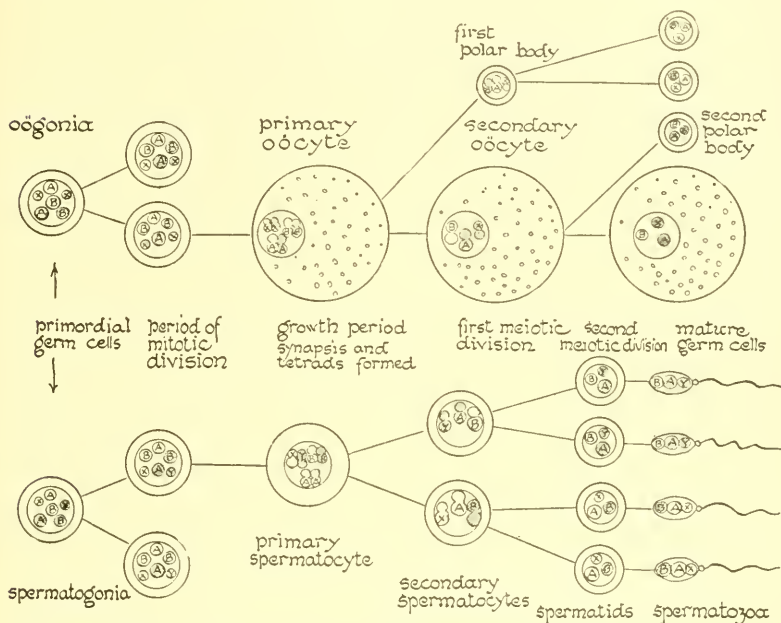


Diagram illustrating meiosis and the maturation of the germ cells. Explain how a constant number of chromosomes is maintained for a given species. (After Curtis and Guthrie.)

certain cases of the pair of so-called *sex chromosomes*. The spermatogonium has now been transformed by this process into a *primary spermatocyte*. When mitosis takes place each chromosome instead of being split longitudinally as in the case of normal mitosis becomes separated so that one entire member of each pair of homologous chromosomes is passed to each daughter cell. This brings about an actual reduction of the numbers of chromosomes present in each daughter cell by one half. This division (*meiosis*) is spoken of as the *reduction division* and the number of chromosomes as the *haploid number* in contrast with the normal or *diploid number* found in all

other cells. Each of the daughter cells is now a *secondary spermatocyte* producing two *spermatids* by the next division in which each of the remaining chromosomes, as in usual mitosis, splits longitudinally in half, thus maintaining the haploid number in each cell. Each spermatid eventually undergoes a metamorphosis into an active sperm without further cell divisions. Thus, each primary spermatocyte produces four functional sperm.

Formation of Ova — Oögenesis

Oögenesis differs from spermatogenesis only in certain essential respects, although the corresponding stages must necessarily be designated differently. Thus the primary germ cells produce *oögonia* which in turn produce *primary* and *secondary oöcytes*, *polar bodies*, and finally *ova*. In the period of growth intervening between the oögonium and its transformation into a primary oöcyte there is a large accumulation of stored food and an accompanying increase in size. In the next stage, when the primary oöcyte undergoes its reduction division the resulting cells are of unequal size, one becoming much larger than the other, having monopolized all of the yolk. The smaller one is in reality an aborted secondary oöcyte and is called the *first polar body*. The second maturation division again results in the formation of a relatively large egg and a tiny *second polar body*. Sometimes the first polar body likewise undergoes division, forming a total of three small polar bodies and one large ovum.

The process of fertilization brings together the male and the female pronuclei, each of which contains the haploid number of chromosomes. By this means the diploid number, or full complement of chromosomes, is restored. Each chromosome, moreover, is composed of a number of *genes* arranged on it like a string of beads. The manner in which this mechanism functions in bringing about variations in the offspring will be considered in the unit on genetics (page 457).

The New Embryology

The question as to just how far back one can trace the developmental pattern of an embryo is one which has long fascinated the zoologist. Great strides along this line have been made in recent years by the students of experimental embryology. We know that fertilized ova develop with great rapidity into well-formed embryos, characterized first by germ layers, later by tissues, and finally by

systems of organs. The modern experimental embryologist raises the specter of the old controversy of *epigenesis* or *preformation*, by inquiring into the question of how much of the development is dependent upon the contents of the fertilized egg and how much is due to environmental factors.

Genes

All of the evidence which has been gathered to date indicates that the development of an embryo is a highly complicated process. As a starting point one might mention the character-controlling *genes* of the chromosomes that are brought together in the formation of a zygote. The vital part which these play in altering developmental patterns has been clearly demonstrated many times.

Environment

The second important factor is the environment. Changes in the normal environment frequently result in abnormalities. It is well known that temperature is a vital factor, since in all except viviparous, warm-blooded forms, a change in temperature will affect the rate of development. Under some conditions, for example when gastrulation is occurring, atypical forms may result. Likewise variations in temperature may produce apparent changes in the genes themselves. When certain kinds of fruit flies are kept at a higher temperature, there is a decrease in the number of ommatidia produced in each eye. Subsequent breeding experiments and a lowering of the temperature, however, result in a return to the original type. Another example of the environmental influence which upsets the normal metabolism of the embryo so that abnormalities result may be seen in the alteration of the oxygen, or food supply. The introduction of poisons also has similar effects.

Changes in the metabolic rate of an organism are definitely correlated with environmental factors as shown by the work of Child and his associates, who demonstrated the presence of definite "*metabolic gradients*." The *axial gradient theory* accounts for differences in dominance of certain areas in the developing organism, beginning with the axis occurring between the two poles of an egg. The dorsal lip of the blastopore soon becomes established as the region of greatest metabolic activity and so determines the rate of development of the other parts. It is at this region of highest metabolic activity that the

head develops. Such differences in metabolic rates between different parts of an organism have been demonstrated experimentally and it is probable that they are related to differences in the oxygen supply.

Natural Potencies

Great differences normally occur between the so-called "potencies" of various species of eggs. Some species of animals produce *totipotent eggs*. These are eggs in which the formative material is equally distributed throughout the component cells, or *blastomeres* during early development. The resulting cleavage is called *indeterminate* because all cells up to a certain stage are totipotent, a condition that may be demonstrated by separating the various blastomeres, for example, from the two-celled to the sixteen-celled stage in some of the jellyfish, and securing normal, though perhaps dwarfed, individuals from each. Cleavage in man is apparently of this type, and is the logical explanation of the production of *identical* twins.

In the case of non-totipotent species the cleavage pattern is said to be *determinate*. There is little doubt that many of the determinative factors are already present in the cytoplasm of an egg before it is fertilized. In such forms as the mollusc, *Dentalium*, or the tunicate, *Styela*, the cytoplasm of the egg itself appears to be arranged in a definite pattern with respect to its future development. In such cases the early separation of blastomeres results in the formation of partial embryos.

Organizers

Certain parts of embryos are called *organizers* because they appear to be more or less directly responsible for the development of other closely associated regions. Much experimental work has been done abroad by Spemann and his co-workers, and in this country by Harrison and his students, all of which demonstrates the presence of such organizers. Perhaps one of the most important organizers is the dorsal lip of the blastopore. That this region is normally associated with the development of a neural plate may be demonstrated by transplanting it to a region beneath the ventral ectoderm of a frog's gastrula, where one would normally expect the formation of epidermis, but instead an aberrant neural plate appears. Such experimental evidence has been most carefully checked and rechecked by all manner

of transplantation experiments. Naturally the stage of development reached at the time of transplantation affects the results obtained. Much work, however, remains to be done in this fascinating field.

SUGGESTED READINGS

Huxley, J. S., and DeBeer, R. G., *Elements of Experimental Embryology*, The Macmillan Co., 1934.

Scientific but readable account of modern embryology.

McEwen, R. S., *Vertebrate Embryology*, rev. ed., Henry Holt & Co., 1931.

A standard elementary text for reference.

Morgan, T. H., *Embryology and Genetics*, Columbia University Press, 1934.

Popularly written attempt to tie up modern embryology and genetics.

Patten, B., *Early Embryology of the Chick*, 3rd ed., P. Blakiston's Son & Co., 1929.

Excellent account of avian development.

Richards, A., *Outline of Comparative Embryology*, John Wiley & Sons, Inc., 1931. Pp. 20-90.

Wells, H. G., Huxley, J. S., Wells, C. P., *The Science of Life*, Doubleday, Doran & Co., 1934. Pp. 150-159.

Popular account of human development.

THE GREAT RELAY RACE

PREVIEW. Seed and soil · Independence of the germplasm · Lines of approach · The experimental method : The usefulness of hybrids ; Mendelism ; what Mendel did ; monohybrids, dihybrids, trihybrids, and other crosses : Unit characters and factors, modified ratios, different kinds of factors · Practical breeding : Selection, mass selection, pedigree breeding, progeny selection ; inbreeding and cousin marriage ; outbreeding and hybrid vigor ; asexual propagation · The germplasmal method : Chromosomes ; genes ; linkage and crossing-over ; chromosome maps · The rôle of cytoplasm · Sex in heredity · Suggested readings.

PREVIEW

“Now these are the generations of Pharez: Pharez begat Hezron, and Hezron begat Ram, and Ram begat Amminadab, and Amminadab begat Nahshon, and Nahshon begat Salmon, and Salmon begat Boaz, and Boaz begat Obed, and Obed begat Jesse, and Jesse begat David.”

As will be remembered, along came Ruth at the Boaz stage and injected a welcome bit of romance into these dry statistics. It is not, however, the vivid story of this Moabite woman, who was in her day so young and charming, that is the reason for introducing this quotation from the Book of Ruth, but rather the bare record of names in itself, together with the indispensable “begats,” that claims our immediate attention now. The generations of mankind have always been hooked up in this chainlike fashion. The spark of life has always been borne forward for certain intervals of time by individuals, and then transmitted to individuals of another generation to carry on. This is the *Great Relay Race*, participated in alike by all human beings, lower animals, and plants. It depends upon the co-operation of long lines of separate mortal individuals who play their temporary part and then inevitably die, while the immortal enduring line of life itself persists. *The science of genetics attempts to explain how such a relay race is run.*

A single microscopic streptococcus, a solitary wandering housefly, or a chance weed pulled up from the wayside, each can boast of a longer pedigree than can the King of England. This universal

principle of continuous inheritance, although not always recognized, has been used and practiced as an art from the beginning, not only in the case of man himself, but also with domestic animals and cultivated plants. The real factors of heredity, however, together with the orderly "laws" which indicate their manner of working, have not been analyzed and made into a science until within comparatively recent times. The very word "genetics" was first employed by Bateson in 1906.

To agree in advance to conduct any would-be excursionist down the rapidly flowing genetic river to a definite landing place is both presumptuous and unwise, for there are at present too many long, uncharted stretches and too much that is unknown to make positive textbook promises of this kind probable of fulfillment. Nevertheless, the general direction in which the river of genetics flows, in spite of its shifting changes, is plain to all, and the tales of returning travelers invite us to intellectual adventure. Students in this field today, however, must make up their minds at the start to be alert explorers and ambitious pioneers, rather than passive, personally conducted excursionists.

Seed and Soil

In the relay race of heredity the continuous thing that is handed on from generation to generation is not the lighted torch, but rather something that corresponds to a box of matches with which another torch may be lighted. Biological inheritance, unlike legal inheritance by which material possessions are transferred from parents to children, consists in the transmission of *genes*, or ultra-microscopic chemical units possessing the uncanny capacity, under suitable conditions, of expanding into visible structures or traits that resemble those in the parental make-up.

Heredity binds the generations together and is absolutely essential, but in itself it is not enough. The potent genes, which are the determiners of heredity, must have a suitable setting in which to unfold their potentialities. This necessary setting is called the *environment*. It expresses and represents the spread that occurs within the limits of the hereditary possibilities, for the hereditary pattern may be enhanced or dwarfed in its expression by the action of the environment. Stated another way, the environment does not *change the quality of hereditary characters*, although it makes possible either a greater or a lesser development of them.

Long ago Semper demonstrated, for example, that the size to which fresh-water snails will grow is somewhat dependent upon the spaciousness of the aquarium in which they are kept, and Baur has shown that red-flowering primroses may be made to produce white flowers if subjected to continuous high temperature (30° C.) for a week or so immediately before blooming.

The heredity factor is so important, nevertheless, that organisms can after all breed only their own kind, regardless of the environment in which they are placed. It is quite as futile, therefore, to argue the relative importance of heredity and environment as it would be to debate which of the two surfaces of a sheet of paper is more essential in making it a sheet of paper. Naturally the biologist is impressed with the contribution which heredity makes in the formation of a new individual, while the sociologist, as would be expected, emphasizes the environmental factor. Although no seed is so poor that it may not be improved by good soil and nurture, and no seed is so good that it will not imperfectly develop in poor soil, yet it is not within the capacity of tares under any circumstances to produce wheat, nor can we expect dogs to engender cats. Former President Lowell of Harvard once said, "There is a better chance to raise eaglets from eagle eggs in a hen's nest, than from hen's eggs in an eagle's nest." Neither heredity nor environment is effective alone. In the formation of any individual organism, the environment is the force that works from without *in*, while heredity works from within *out*. Both are as indispensable in producing a plant or an animal as land and water are in the formation of a shore line.

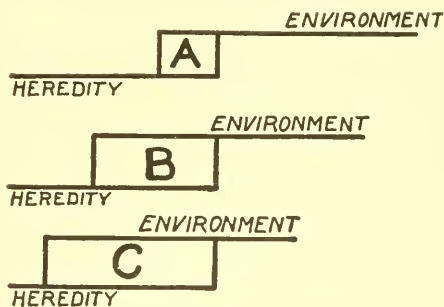
Moreover, there is *extra-biological* or *social inheritance* to reckon with, that makes us the "heirs of the ages." Civilization in itself may be regarded as the collective achievements of mankind, and as time goes on these environmental collections multiply and accumulate. We live today, for example, in a world of skyscrapers, automobiles, stock exchanges, airplanes, chain-stores, movies, ocean liners, and radios, the acquisition of which our ancestors of three hundred years ago never even dreamed of. If we may seem to have a larger horizon and to see farther than our ancestors, it is not so much because we are taller than they were, as it is because we stand on their shoulders with respect to these extra-biological acquisitions.

There is no doubt that the environment of mankind has undergone more modification than human heredity has. When we consider, for example, the intellectual and artistic output of ancient Greece, a small

country in classical times with restricted environment, and contrast it with the corresponding output of the whole enlarged modern world, with its highly elaborated setting, there is occasion to wonder whether the intrinsic capabilities of man have increased as much as his opportunities. It has always been easier for man to modify his surroundings than to control his own heredity. To quote Joseph Jastrow, the psychologist, "The fact that modern schoolboys are far better equipped to withstand, utilize, and control the forces of nature than was Aristotle, is not due to the superiority of the schoolboys, but to the contributions of the Aristotles of past generations."

Furthermore, the range of hereditary possibilities, particularly in the case of man, may be considerably influenced by training or education, which is a hopeful factor that perhaps cannot be entirely accounted for either by heredity or environment. Education in itself forms no part of the hereditary stream, since it is only the *capacity to acquire education in a proper environment* that can be handed on from parent to child. In the case of plants, and those animals whose automatic instincts make it unnecessary for them to learn how to live, the factor of training or education does not play as dominant a part as in man.

In the accompanying diagram an attempt has been made to indicate the mutual dependence of heredity and environment, in the formation of three different hypo-



A "slide-rule" diagram, showing how the interplay between heredity and environment may result in different individuals, A, B, and C.

thetical individuals, A, B, and C, represented by the rectangles in the figure. When the parallel edge indicating the environment is shoved back and forth, like a slide rule, different-sized rectangles result. The act of shoving, particularly when the slide rule is shortened and the "rectangular individual" is consequently enlarged, is much like the process of education or training. In each case it will be noted that neither the whole of the hereditary nor the whole of the environmental edge is involved in the resulting individual. This corresponds with our common observation and conviction that neither our capacities nor our opportunities are all ever entirely utilized.

Independence of the Germplasm

The *germplasm*, or the sexual cells that carry the load of hereditary possibilities, and the *somatoplasm*, which makes up the body of the individual, although to a certain extent dependent upon each other

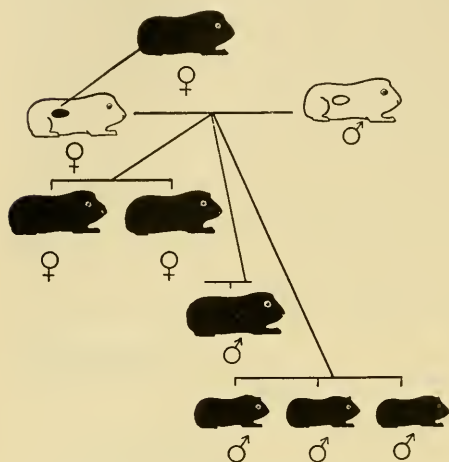


Diagram of ovarian transplantation experiment by Castle and Phillips, to show the lack of somatic influence on the germplasm. The ovaries of a black guinea pig were engrafted into a female albino whose ovaries had been removed. Upon recovery this female was mated three times with an albino male. All the progeny were black. (From Walter, *Genetics*, by permission of The Macmillan Company, publishers.)

a black guinea pig into a white guinea pig whose own ovaries had been removed. Later, after recovery from the operation, when this white female with the borrowed ovaries of the black female was mated with a white male guinea pig, the offspring were *all black*, although both their parents were white, and under ordinary circumstances would produce only white offspring. This shows that temporary residence within a white somatoplasm did not in any way affect the character of the black-producing germplasm that had been grafted into the white body.

The establishment of the fact of the practical ineffectiveness of somatic influence upon the germplasm has far-reaching applications

in a nutritional way, are remarkably independent. Despite the popular idea to the contrary, it is extremely improbable that changes wrought by, or impressed upon, the somatoplasm exercise any modifying influence upon the accompanying germplasm. The somatoplasm is simply like a casket in which the jewel of germplasm reposes. No decoration or elaboration of the casket will have any material effect upon the jewel within.

This point has been convincingly brought out, along with other cumulative evidences, in a critical experiment performed in 1911 by Castle and Phillips. These investigators successfully transplanted the ovaries of

in any theory of heredity. It means that modifications acquired within the lifetime of the individual are not transferred to the parental germplasm, and do not consequently reappear as hereditary characters in the next generation. If this conclusion seems perhaps discouraging to prospective parents who would gladly have whatever success in the building of character, the development of intelligence, or the attainment of artistic or other ability that they have been able to bring about in their own lifetime perpetuated in their children, they may well be reminded of the other side of the picture, namely, that parental failures in accomplishment during life likewise form no part in their children's biological inheritance. Each child, therefore, starts out with his ancestral biological inheritance unimpaired by either parental failures or successes. In any case, the honest scientifically-minded person is bound to accept the facts whatever they are, if they can be ascertained, regardless of the conclusions to which they lead, rather than to place dependence upon unproven propositions that, with wishful thinking, he would like to believe are true.

It should be pointed out clearly that the only biological opportunity where it is possible to improve the germinal chances of the next generation is not *after* the germinal equipment has already been assigned to the prospective parent from his ancestors, but at the critical time of mating when two streams of germplasm are selected for combination. Picking out the right mother is the most important contribution which any man can make for his future children.

Thus, the individual somatoplasm is simply the guardian and executor of the germinal possibilities committed to its care. Hereditary possibilities do not come directly *from* the parents, but *through* them down the long ancestral line. When and how remote ancestors have picked up the gifts of biological inheritance which they present to posterity forms one of the most intriguing riddles in the science of genetics. It is encouraging to know that the results of modern researches have hopefully opened up the way to a possible answer to this question, which may be more suitably developed later on.

Lines of Approach

There are two fundamental lines of approach to genetics: first, by way of the more visible *somatoplasm* of organisms, and second, the *germplasmal* approach, which involves recourse to microscopic technique. The former approach may be subdivided into at least three lines of attack, namely, observational, statistical, and experimental.

The *observational method* has been practiced from time immemorial, and to it is due most of the accumulations of our general knowledge concerning heredity up to about the turn of the present century in 1900. The phrase "like produces like" expresses the general impression that is gained from observation, although there are plenty of exceptions to the apparent rule. We say that children in a general way "take after" their parents, although there are conspicuous instances when it becomes necessary for parents to "take after" their children, in order that they may be made to conform to a family tradition, whatever it may be. It is repeatedly observed that not only individuals of one generation may be in general *like* their predecessors, but that certain noticeable characteristics in the make-up of an individual may occur more often in some family lines, breeds of animals, or strains of plants than in the general population of which they are a part. Whenever this is so we are led to suspect, even when we may not be entirely convinced, that such characteristics are hereditary. General but more or less vague observations of this sort, while useful in establishing the simple fact of inheritance, do not go very far in determining and analyzing the causes of heredity and the laws of procedure that underlie the mechanism of inheritance, which it is necessary to know in order to establish a real science of genetics.

The *statistical method* recognizes the desirability of arranging qualitative data in quantitative terms, as a necessary process in reducing random observations and guesses to definite scientific form. Recourse must always be made to mathematical treatment in formulating any science, and genetics is no exception. Mathematics, however, is simply a useful tool to be employed in arranging the facts and in bringing them together in convenient form for interpretation. There are repeated occasions when it is not only desirable but indispensable to focus isolated and scattered facts into a single comprehensive picture which can only be accomplished by statistical treatment. Statistics, however, to be of value in solving problems of heredity, must be based upon careful observations and accurate measurements previously obtained. *Biometry*, the science of measurement when applied to biological data, is powerless to extract true conclusions out of faulty observations or findings.

The biometrical approach is about the only way available in which to investigate the problems of heredity as applied to mankind. It is obviously not feasible, even if it were desirable, to plan and execute controlled experiments in human breeding, of sufficient magnitude

and duration, to be of general significance in establishing the laws of inheritance. Not only would any such ambitious program take too many generations to reach any satisfactory conclusions, even if it were possible, but also it would involve too many insuperable social difficulties. In the case of mankind, therefore, we are forced to resort to experiments in marriage and other sexual relations that have already been made in the past, for collecting data, and this type of investigation demands the technique of statistical treatment.

The third method of approach in storming the citadel of genetics is the *experimental method*. This has proven to be very successful. By controlling breeding of animals and plants and observing the outcome, which is not open to the objections encountered when human material is employed, it has become possible to find out much concerning the *modus operandi* of inheritance. The same biological laws and procedures that are found to be true of plants or animals may then, to a large extent at least, be applied to man. This method will be elaborated somewhat in the following sections.

All of these methods, namely, observation, statistical treatment, and experimental breeding, are concerned primarily with somatoplasms. The *germplasmal method* of approach, on the other hand, is concerned with the concealed beginnings of the life story, rather than with its visible sequel in the bodies of organisms. The germplasmal approach has to do with the astonishing behavior of the genes, which are the determiners of subsequent somatoplasmal manifestations. This underground phase of the heredity problem is proving in recent years to be most illuminating, and some consideration of it, together with the experimental method just mentioned, will make up the essential remaining part of this section on genetics.

The Experimental Method

The Usefulness of Hybrids

In order to learn the secrets of inheritance by the controlled crossing of plants and animals, it is necessary to use parental stocks that differ from each other in some of their characteristics. When this is done, *hybrids* are produced in which the respective contributions to the offspring from the two parents may be determined, and thus the first steps made in the analysis of the problems of inheritance.

If both parents and the consequent offspring are alike, then a colorless monotony results that gives no differential clue as to how heredity

works. Just as in the evolution of species during long periods of geological time, *variation* must somewhere have entered in to make it possible that an elephant and a mouse could have arisen from a common, remote ancestor, so in the relay race of heredity we cannot picture the details of how a succession of generations comes about, when all the individuals concerned are alike. The uniform bulk of inheritance passes unnoticed. It is only the "sore thumbs" of variation that stand out, for although hereditary succession may and does occur in the absence of variation it is only when a visible variable is introduced from one parent or the other, that we can see how the inheritance of a characteristic jumps from one side of the house to the other, skips a generation, doubles up, or behaves in some other manner. One outstanding way in which hybrid variation is brought about in nature is by sexual reproduction, in which two different streams of germplasm unite to form a new generation.

Pure hereditary strains, on the other hand, are probably not nearly as common in nature as are hybrids. In self-fertilized plants, for example, we may not expect to find much in the way of hereditary variation, since no different outside germplasmal potentialities have been introduced in the production of offspring. Likewise, in parthenogenetic organisms, which develop progeny without any contribution from the male parent, as well as in all kinds of asexual propagation, where a fragment of the parental body gives rise without germinal modification to a new individual, one may expect to encounter monotony so far as hereditary variations are concerned. Transient variations that are induced by environmental causes, like the tanned skin of a lifeguard at the seashore, or the luxuriant growth of a pigweed on a manure pile, do not carry over in heredity. That hereditary variations frequently do appear in the absence of hybrid combinations is to be accounted for by the occurrence of *mutations*, or spontaneous hereditary variations, which are mentioned in the section on Evolution.

In the early days of the nineteenth century, certain scientifically-minded botanists in Europe began to explore the possibilities of hybridization by artificially crossing plants. Koelreuter (1733-1806) and Gaertner (1772-1836) in Germany, Naudin (1815-1889) in France, and Knight (1759-1839) in England were conspicuous pioneers in this field of experimentation. It remained, however, for Gregor Johann Mendel (1822-1884) of Austria to become the master hybridizer of them all, and to carry his experiments through to results

and conclusions that mark him as the patron saint of the modern science of GENETICS.

Mendelism

Gregor Johann Mendel, with peas and arithmetic, not only demonstrated the existence of an orderly system of inheritance that bears his name, but was himself a living example of the extent to which innate hereditary ability can dominate an environment none too favorable. He was an Augustinian monk, attached to a monastery in Brünn, Austria (now Brno, Czechoslovakia), where, with ordinary garden peas, he carried through a remarkable series of breeding experiments extending over several years. During the first part of his career, when working on these famous experiments, he was handicapped by having only a small patch of a cloister garden in which to operate. Later on, when he finally became abbot of the monastery and could control garden space at will, he was necessarily so occupied with the administrative duties of his office that he did not have much time to devote to scientific pursuits. Yet, in spite of these limitations, and regardless of the fact that his associates were not particularly sympathetic with his unpriestly avocations, he carried to completion by himself this remarkable piece of fundamental investigation which insures for him a permanent place in the biological Hall of Fame.

His results were finally published in 1866 in the obscure "Proceedings" of a small, unimportant local Natural History Society. They did not at the time gain appreciative attention and were promptly forgotten, due in part perhaps to the preoccupation of the scientific world at the time with the newly launched *Theory of Natural Selection* (1859) of Charles Darwin. Unrecognized and unknown, Mendel died in 1884, with the confident declaration on his lips, "Meine Zeit wird schon kommen!" Some years later this prophecy came true when, in 1900, three scientists, Correns in Germany, von Tschermak in Austria, and DeVries in Holland, independently rediscovered Mendel's forgotten contribution, and because of it, initiated the remarkable era in the study of heredity that has resulted in establishing the science of Genetics as we know it today.

What Mendel Did

Mendel's genius is shown by the fact that he did not make his experiments blindly, but set for himself the clearly defined problem

of reducing the phenomena of inheritance to a measurable mathematical basis. For this purpose he wisely chose for experimentation garden peas, which not only are easily grown, but also possess readily recognized constant characteristics. Since peas are normally self-fertilized, they represent at the start comparatively pure hereditary strains. Moreover, hybridization in peas can be controlled from contamination by insects. Since fertilization occurs before the flowers open, the hooded structure of the flowers is such that interference from their chance visits is prevented. As is well known, insects may carry on involuntary hybridization experiments of their own in connection with many plants, by transferring pollen grains from the stamen of one flower to the stigma of another.

Instead of considering the whole complex individual in the light of a "hybrid" unit, as former hybridizers had done with much resulting confusion, Mendel focused his attention upon single alternative characters, *one pair at a time*, that were unlike in the two contributing parents. This simplification of the problem made the collection of data less complicated, and the analysis of results possible. Finally, he not only combined single pairs of characters into hybrids, but he went further and followed up the results obtained by breeding these known hybrids together through several generations, meanwhile taking meticulous pains to account for *all* the offspring of whatever sort in each case, so that ratios of relative occurrence could be computed. For example, he dealt with seven pairs of alternative characteristics found in different strains of peas, as follows :¹

1. Smooth seeds or wrinkled seeds ;
2. Yellow seed-coats or green seed-coats ;
3. Tall vines or dwarf vines ;
4. Colored flowers or white flowers ;
5. Axial flowers or terminal flowers ;
6. Inflated pods or constricted pods ;
7. Green pods or yellow pods.

In every case when these pairs of characters were put together the hybrids thus produced were not intermediate in appearance, but were alike, and resembled one of the parents and not the other. When these hybrids in turn were interbred with each other, or allowed to be normally self-fertilized, which amounts to the same thing, the

¹ Dr. O. E. White, of the Brooklyn Botanical Garden, as early as 1917 reported thirty-four pairs of hereditary characters in peas on which determinative experimental studies have been made.

progeny always fell into two groups in appearance like the two grandparents, in the ratio of 3:1. Thus, when smooth peas were artificially crossed with wrinkled peas, the hybrids were all smooth peas, and when these smooth hybrids in turn were allowed to cross *inter se*,

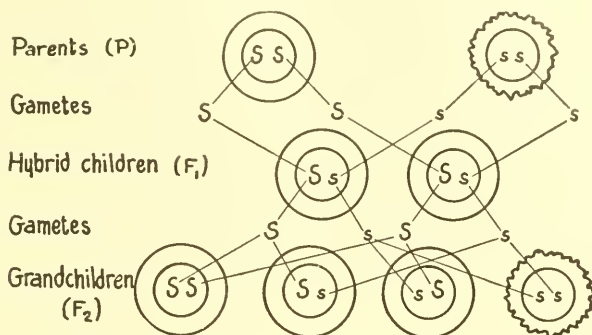


Diagram of the ancestry and progeny of a typical monohybrid, formed from smooth and wrinkled garden peas. The inner circles represent germplasm, enclosed in the outer circles, or somatoplasm. S, determiners of smooth peas; s, determiners of wrinkled peas.

the resulting grandchildren could be grouped in the ratio of three smooth peas to one wrinkled pea. These results are indicated diagrammatically in the accompanying figure, with the smooth characteristic represented by a single letter as S, and the wrinkled kind by s. The germinal make-up of each individual is thus represented by two letters, since it is always derived from two parental gametes.

If smooth and wrinkled gametes come together in the same individual, the smooth determiner covers up, or "dominates," the wrinkled one, and is consequently called a *dominant*, while the wrinkled gamete recedes from visible expression for the time being, and is designated as a *recessive*. Which one of the alternate pair of parental characters will be dominant and which recessive in the offspring in any given case cannot be learned in advance by inspection. It is, therefore, necessary to resort to the breeding test in order to make the determination.

Further crosses on Mendel's part showed that SS peas were pure stock, like one of the grandparents with which he started, and when interbred produced only SS peas, although coming from impure or hybrid parents. Similarly the ss peas were also pure like the other grandparent, and likewise always gave rise only to ss peas when allowed to inbreed with their own kind. The hybrid Ss peas, on the

other hand, being constituted like their hybrid parents, when interbred furnished again the typical 3:1 ratio. In Mendel's original experiments there were actually obtained from the *Ss* peas 5474 smooth and 1850 wrinkled peas, which is very near the expected 3:1 ratio.

Such pure *SS* peas and hybrid *Ss* peas are said to be *phenotypically* alike and *genotypically* different. That is, they *look alike*, but have different possibilities when it comes to producing *gametes*. The way to distinguish the one from the other is to *breed them back with the recessive ss* peas, which can conceal nothing, and observe the kind and proportion of the offspring produced. *SS* × *ss* gives 100 per cent *Ss* (phenotypically smooth), while *Ss* × *ss* gives 50 per cent *Ss* (phenotypically smooth) and 50 per cent *ss* (phenotypically wrinkled), as shown in the checkerboard below, in which the *gametes* of the two sexes are placed outside the double lines, and the resulting kinds of individuals are represented by double letters within the squares.

	<i>S</i>	<i>S</i>
<i>s</i>	<i>Ss</i>	<i>Ss</i>
<i>s</i>	<i>Ss</i>	<i>Ss</i>

	<i>S</i>	<i>s</i>
<i>s</i>	<i>Ss</i>	<i>ss</i>
<i>s</i>	<i>Ss</i>	<i>ss</i>

Sometimes dominance may be incomplete, in which case it is not necessary to back-cross with the corresponding recessive in order to determine which are pure and which are hybrid dominants. The four-o'clock (*Mirabilis jalapa*), as pointed out by Correns, furnishes a well-known demonstration of this point, for the hybrid produced by red × white flowers is not dominant red, as might be expected, but *pink*. The pink hybrids give in turn the proportion of three colored flowers (one red and two pink) to one white.

Mendel carried through the same hybridization procedure and subsequent follow-up, with each of the seven pairs of contrasting characters, and found that the approximate 3:1 result always obtained, regardless of whatever other characters were present in the individual plants. Each pair of characters, in other words, behaved independently of every other pair. This is called the principle of *independent assortment*.

It is apparent, moreover, that the determiner for each character retains its integrity, reappearing in the next generation true to itself, regardless of the company it has been keeping within the germ cell. This integrity of the hereditary determiners, together with the

uncontaminated reappearance of the character in the next generation, is termed the principle of *segregation*.

Thus, out of simple but perfectly controlled experiments with garden peas, Mendel was able to lay down three "laws," namely, *dominance*, *independent assortment*, and *segregation*, which together constitute the essential features of what is known as "Mendelism." These fundamental laws have been confirmed many times over, in a great variety of plants and animals by a host of critical investigators, and their use now makes possible a precise prediction of results in experimental breeding that was quite impossible before their formulation.

Monohybrids, Dihybrids, Trihybrids, and Other Crosses

The fundamental Mendelian laws as illustrated by a *monohybrid*, that is, a hybrid with respect to a single pair of characters, are comparatively simple. When two monohybrids are bred together, as shown in the preceding paragraphs, the resulting progeny occur in the phenotypic ratio of 3 : 1, and the genotypic ratio of 1 : 2 : 1. Dihybrids, trihybrids, tetrahybrids, etc., are increasingly complicated, but are quite understandable when it is remembered that they are nothing more than combinations of monohybrids, resulting from the independent assortment of the characters involved. The expectations for such crosses are shown in the following table :

	NUMBER OF PAIRS OF CHARACTERS	POSSIBLE COMBI- NATIONS WHEN CROSSED	NUMBER OF PHENOTYPES IN PROGENY	NUMBER OF GENOTYPES IN PROGENY
Monohybrid . . .	1	4	2	3
Dihybrid	2	16	4	9
Trihybrid	3	64	8	27
Tetrahybrid . . .	4	256	16	81
Etc.	?	?	?	?

As an example of the way in which a dihybrid works out, *black color* in horses is dominant over *chestnut color*, and *trotting gait* over *pacing*. These two pairs of characters are independent of each other, so that when a black pacer is mated with a chestnut trotter, all the offspring of the hybrid generation will be black trotters, since black color and trotting gait are dominant characters. Then when such *hybrid* black trotters are mated together there will be sixteen possible

combinations, falling into four phenotypic groups, and nine genotypic groups, as shown in the following checkerboard, in which the double gametes of the dihybrid parents are represented outside the double lines, and their combinations in the offspring indicated within the sixteen squares. The arbitrary symbols used are, *B* (black); *b* (chestnut); *T* (trotter); *t* (pacer). It will be seen from the checkerboard that

DIHYBRID CHECKERBOARD

	<i>BT</i>	<i>Bt</i>	<i>bT</i>	<i>bt</i>
<i>BT</i>	<i>BT</i> <i>BT</i>	<i>BT</i> <i>Bt</i>	<i>BT</i> <i>bT</i>	<i>BT</i> <i>bt</i>
<i>Bt</i>	<i>Bt</i> <i>BT</i>	<i>Bt</i> <i>Bt</i>	<i>Bt</i> <i>bT</i>	<i>Bt</i> <i>bt</i>
<i>bT</i>	<i>bT</i> <i>BT</i>	<i>bT</i> <i>Bt</i>	<i>bT</i> <i>bT</i>	<i>bT</i> <i>bt</i>
<i>bt</i>	<i>bt</i> <i>BT</i>	<i>bt</i> <i>Bt</i>	<i>bt</i> <i>bT</i>	<i>bt</i> <i>bt</i>

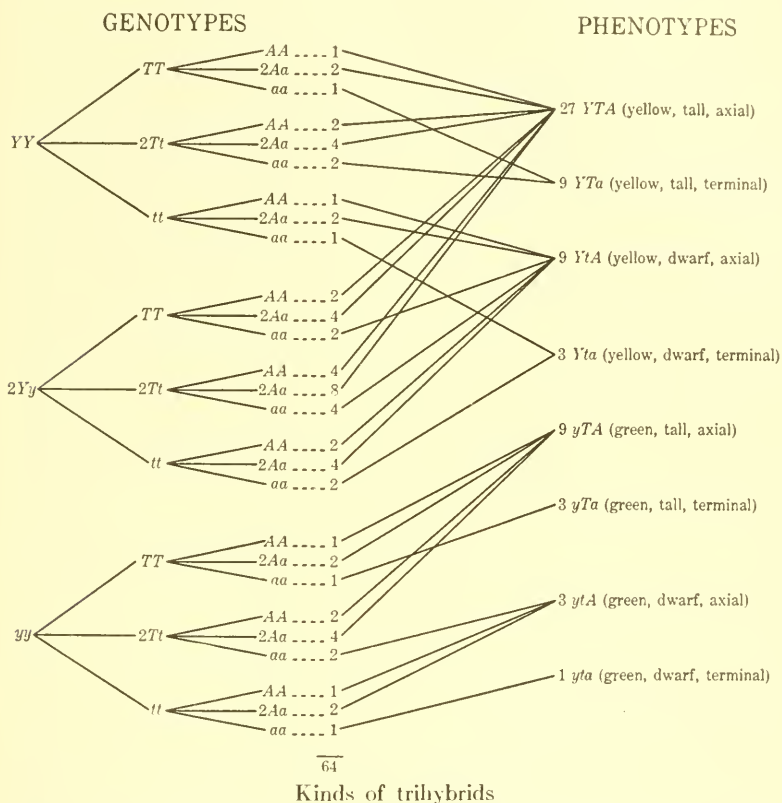
nine chances out of sixteen are possible that a *black trotter* will result, since both *B* and *T* are present at least once in their make-up. There are three chances that a *black pacer* (*Bt*) will occur, three chances for a *chestnut trotter* (*bT*), and one chance in sixteen that the dihybrid parents will produce a *chestnut pacer* (*bt*). Thus, the phenotypic ratio in the case of a dihybrid is typically 9:3:3:1. The checkerboard further shows that the sixteen possibilities fall into nine genotypic, or actually different, groups represented by different combinations of the four symbolic letters within the squares.

The expectation when two trihybrids are crossed is shown by

TRIHYBRID CHECKERBOARD

	<i>YTA</i>	<i>YT<i>a</i></i>	<i>Y<i>t</i>A</i>	<i>Y<i>t<i>a</i></i></i>	<i>yTA</i>	<i>yT<i>a</i></i>	<i>ytA</i>	<i>yt<i>a</i></i>
<i>YTA</i>	<i>YTA</i> <i>YTA</i>	<i>YTA</i> <i>YT<i>a</i></i>	<i>YTA</i> <i>Y<i>t</i>A</i>	<i>YTA</i> <i>Y<i>t<i>a</i></i></i>	<i>YTA</i> <i>yTA</i>	<i>YTA</i> <i>yT<i>a</i></i>	<i>YTA</i> <i>ytA</i>	<i>YTA</i> <i>yt<i>a</i></i>
<i>YT<i>a</i></i>	<i>YT<i>a</i></i> <i>YTA</i>	<i>YT<i>a</i></i> <i>YT<i>a</i></i>	<i>YT<i>a</i></i> <i>Y<i>t</i>A</i>	<i>YT<i>a</i></i> <i>Y<i>t<i>a</i></i></i>	<i>YT<i>a</i></i> <i>yTA</i>	<i>YT<i>a</i></i> <i>yT<i>a</i></i>	<i>YT<i>a</i></i> <i>ytA</i>	<i>YT<i>a</i></i> <i>yt<i>a</i></i>
<i>Y<i>t</i>A</i>	<i>Y<i>t</i>A</i> <i>YTA</i>	<i>Y<i>t</i>A</i> <i>YT<i>a</i></i>	<i>Y<i>t</i>A</i> <i>Y<i>t</i>A</i>	<i>Y<i>t</i>A</i> <i>Y<i>t<i>a</i></i></i>	<i>Y<i>t</i>A</i> <i>yTA</i>	<i>Y<i>t</i>A</i> <i>yT<i>a</i></i>	<i>Y<i>t</i>A</i> <i>ytA</i>	<i>Y<i>t</i>A</i> <i>yt<i>a</i></i>
<i>Y<i>t<i>a</i></i></i>	<i>Y<i>t<i>a</i></i></i> <i>YTA</i>	<i>Y<i>t<i>a</i></i></i> <i>YT<i>a</i></i>	<i>Y<i>t<i>a</i></i></i> <i>Y<i>t</i>A</i>	<i>Y<i>t<i>a</i></i></i> <i>Y<i>t<i>a</i></i></i>	<i>Y<i>t<i>a</i></i></i> <i>yTA</i>	<i>Y<i>t<i>a</i></i></i> <i>yT<i>a</i></i>	<i>Y<i>t<i>a</i></i></i> <i>ytA</i>	<i>Y<i>t<i>a</i></i></i> <i>yt<i>a</i></i>
<i>yTA</i>	<i>yTA</i> <i>YTA</i>	<i>yTA</i> <i>YT<i>a</i></i>	<i>yTA</i> <i>Y<i>t</i>A</i>	<i>yTA</i> <i>Y<i>t<i>a</i></i></i>	<i>yTA</i> <i>yTA</i>	<i>yTA</i> <i>yT<i>a</i></i>	<i>yTA</i> <i>ytA</i>	<i>yTA</i> <i>yt<i>a</i></i>
<i>yT<i>a</i></i>	<i>yT<i>a</i></i> <i>YTA</i>	<i>yT<i>a</i></i> <i>YT<i>a</i></i>	<i>yT<i>a</i></i> <i>Y<i>t</i>A</i>	<i>yT<i>a</i></i> <i>Y<i>t<i>a</i></i></i>	<i>yT<i>a</i></i> <i>yTA</i>	<i>yT<i>a</i></i> <i>yT<i>a</i></i>	<i>yT<i>a</i></i> <i>ytA</i>	<i>yT<i>a</i></i> <i>yt<i>a</i></i>
<i>ytA</i>	<i>ytA</i> <i>YTA</i>	<i>ytA</i> <i>YT<i>a</i></i>	<i>ytA</i> <i>Y<i>t</i>A</i>	<i>ytA</i> <i>Y<i>t<i>a</i></i></i>	<i>ytA</i> <i>yTA</i>	<i>ytA</i> <i>yT<i>a</i></i>	<i>ytA</i> <i>ytA</i>	<i>ytA</i> <i>yt<i>a</i></i>
<i>yt<i>a</i></i>	<i>yt<i>a</i></i> <i>YTA</i>	<i>yt<i>a</i></i> <i>YT<i>a</i></i>	<i>yt<i>a</i></i> <i>Y<i>t</i>A</i>	<i>yt<i>a</i></i> <i>Y<i>t<i>a</i></i></i>	<i>yt<i>a</i></i> <i>yTA</i>	<i>yt<i>a</i></i> <i>yT<i>a</i></i>	<i>yt<i>a</i></i> <i>ytA</i>	<i>yt<i>a</i></i> <i>yt<i>a</i></i>

Mendel's garden peas, in which three alternative pairs of characters are selected, namely, yellow (*Y*) and green (*y*) peas; tall (*T*) and dwarf (*t*) vines; and axial (*A*) and terminal (*a*) flowers. The trihybrids in this case will have the genotypic formula *YyTtAa*, and will be phenotypically yellow, tall, and axial. Such hybrids, because of the inde-



pendent assortment of their characters, can produce eight possible kinds of gametes, or mature germ cells, each carrying three characters, as follows: *YTA*, *YTa*, *YtA*, *Yta*, *yTA*, *yTa*, *ytA*, *yta*. When these triple gametes unite, there are sixty-four (8×8) possible combinations, as shown in the accompanying checkerboard, which will fall into eight different phenotypic groups in the ratio of 27 : 9 : 9 : 3 : 9 : 3 : 3 : 1 (total 64), and they may be further classified into twenty-seven genotypically different groups, represented above as three monohybrid ratios combined.

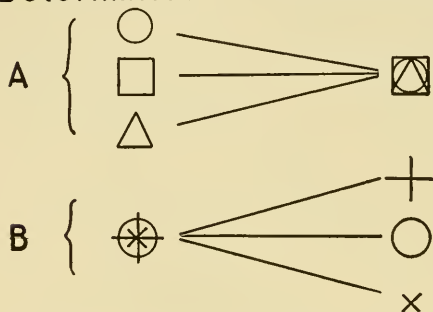
In actual practice, if a combination of three or more characters is desired, *one character at a time* in either pure dominant or recessive form is obtained. By this method, since the expectation of either a pure dominant or a pure recessive in a monohybrid is one out of four, early realization of the desired combination is likely.

Unit Characters and Factors

A great deal has been learned about heredity through the experimental breeding of plants and animals since Mendel's laws became available. Many of the facts gained, however, are at first sight in apparent contradiction to these laws, but the value of the fundamental concepts of *dominance*, *independent assortment*, and *segregation* in the

Hereditary Determiners

Somatic Characters



interpretation of inheritance remains unquestioned. Any adequate consideration of the apparent departures from the clear-cut conclusions of Mendelism would require many more pages than are available in this book.

For one thing, Mendel's experiments led him to the idea of *Unit Characters*, each sponsored by a single germinal determiner. There is now abundant evidence that whatever it is in the

Diagram of the relation between hereditary determiners and resulting somatic characters. *A*, three or more determiners may combine to produce a single visible character, or *B*, a single hereditary determiner may find expression in a number of different somatic characters.

germplasm that, under suitable environmental conditions, becomes eventually expressed as a single character, it is often made up of more than one unit. This discovery has led to the development of the *factor hypothesis*, which implies that there is usually, if not always, an interplay between different hereditary *factors* in determining the contribution which inheritance furnishes to the formation of a character in an individual. Moreover, a constellation of interacting hereditary factors may be responsible, in certain instances, for the expression of more than one visible character.

MODIFIED RATIOS. The existence of factors, or fractional rather

than unit determiners, is particularly apparent when, for example, the typical dihybrid ratio of 9 : 3 : 3 : 1 becomes modified into other than the usual phenotypic groups. The following ratios have been demonstrated in various dihybrid crosses: 3 : 6 : 3 : 1 : 2 : 1, 9 : 3 : 4, 10 : 3 : 3, 12 : 3 : 1, 9 : 6 : 1, 9 : 7, 10 : 6, 13 : 3, and 15 : 1. In each of these cases it is still a dihybrid, made up of two monohybrids and totaling sixteen possibilities involved.

To work out a single illustration of how the factor idea gives rise to a modified phenotypic ratio, let us take Bateson's famous case of sweet peas, that resulted in the 9 : 7 ratio of flower color. Bateson dealt with two different strains of white-flowering sweet peas that bred true to the white color as long as they were not out-crossed. When the two white strains were artificially crossed with each other, however, all the progeny in the first generation produced *purple flowers*. This purple color was found to be due to the combination of two factors, which may arbitrarily be designated as *A* and *B*, one of which was furnished by each parental strain. Neither factor alone could produce the purple color since the parents were both white. When the purple hybrids in turn formed their possible kinds of gametes and were crossed with each other, there resulted the customary sixteen combinations of a dihybrid, as shown in the checker-board. *Aabb* (white) \times *aaBB* (white) = *AaBb* (purple). Gametes from *AaBb* = *AB*, *Ab*, *aB*, *ab*.

	<i>AB</i>	<i>Ab</i>	<i>aB</i>	<i>ab</i>
<i>AB</i>	<i>ABAB</i>	<i>ABAb</i>	<i>ABaB</i>	<i>ABab</i>
<i>Ab</i>	<i>AbAB</i>	<i>AbAb</i>	<i>Ab aB</i>	<i>Ab ab</i>
<i>aB</i>	<i>aBAB</i>	<i>aBAb</i>	<i>aBaB</i>	<i>aBab</i>
<i>ab</i>	<i>abAB</i>	<i>abAb</i>	<i>abaB</i>	<i>abab</i>

Of the sixteen possibilities, the nine possessing at least one *A* factor and one *B* factor produced purple flowers, while the remaining seven, which did not possess both the *A* and *B* factors, were white. It will be seen that the seven phenotypically white-flowering possibilities fall into three genetically different groups, namely, 3 *AAbb* or 3 *Aabb*, 3 *aaBB* or 3 *aaBb*, and 1 *aabb*. By breaking up the seven kinds of white-flowering sweet peas into the genetically different groups 3 : 3 : 1, and adding them to the nine purple-flowering kinds, the underlying Mendelian dihybrid ratio of 9 : 3 : 3 : 1 is restored. This

is a case of *complementary factors*, because one factor is required to complement the other in order to bring the character into expression while neither is effective alone.

DIFFERENT KINDS OF FACTORS. There are also *supplementary factors*, where one factor alone may produce a visible effect, but a second factor may change its manifestation; or *inhibiting factors*, where the expression of a factor is prevented by the interference of another; or *duplicate factors*, where separate "doses" of the same thing combine to produce a cumulative effect; or *lethal factors*, which are so disharmonious that if they arrive together from *both* parental sources, the unfortunate individual sooner or later dies, although able to survive when only a single lethal factor comes from one parent; or *sex-linked factors*, that are tied up with either the maternal or the paternal side of the house. In all these cases the factors in their behavior obey the fundamental Mendelian laws, although the resulting ratios furnish intriguing complications that Mendel himself did not anticipate.

It is hoped that the reader will be stimulated to explore in books devoted primarily to Genetics (see bibliography) further than the general survey presented in this chapter.

Practical Breeding

Selection

Long before Mendel pointed the way by which to control the operations of heredity, man was active in fixing desirable characters in animals and plants by means of *artificial selection*, and in doing this was only following in the footsteps of Mother Nature, who has been exercising "natural selection" from time immemorial. Many of the forms selected and nurtured by man never could have survived if left to the more exacting demands of nature.

We know today, thanks to Mendel, that phenotypes do not always reproduce their own kind, and that the genotype is the all-important thing to get at in heredity. It must be admitted, however, that in spite of difficulties encountered, our pre-Mendelian forebears, in establishing lines of domesticated animals and cultivated plants by the method of blind selection of phenotypes, attained a remarkable degree of success. Even the ancient lake-dwellers of prehistoric Switzerland, it is said, developed ten different kinds of cereals from wild plants.

There are three different methods of phenotypic selection which are

still practiced with gratifying results by practical breeders, namely, mass selection, pedigree breeding, and progeny breeding.

MASS SELECTION. In mass selection a general population, exhibiting desirable qualities on the average, is drawn upon to furnish progenitors for the following generation in the faith that "like produces like." There are two ways in which a desirable population to breed from may be obtained. A crop, for example, may be grown under the most favorable conditions of cultivation and environment and the improved individuals resulting chosen as seed. This method of procedure is based upon the questionable belief that acquired characters reappear in the next generation. Or the same crop may be grown *under adverse conditions* and those individuals which are phenotypically most promising chosen, with the idea that, since they have made good in spite of unfavorable surroundings and poor nurture, they must obviously possess desirable inherent or hereditary qualities.

The limitations of this common practice of mass selection lie in the fact that selection must be made over and over again, since nothing dependable has been established. Moreover, the best individuals in this wholesale procedure are often swamped by the average ones, so that all are reduced to a mediocre level.

PEDIGREE BREEDING. Pedigree breeding, based likewise upon the fallacy that like always produces like, narrows selection definitely to single individuals or lines, rather than hopefully employing a confusion of many unknown lines. It is a method that has been particularly successful in breeding race horses and various kinds of domestic animals, and depending upon stud-books and zealously recorded pedigrees. Even human beings are known to indulge in "blue books" and proud genealogical records that characterize pedigree breeding.

PROGENY SELECTION. Progeny selection depends upon the principle that the only way to determine the character of the essential germplasm in plants and animals is to see *what kind of somatoplasms it produces*. In the poultry pens at the Massachusetts Agricultural Station at Amherst, for example, Hays and Sanborn established a strain of hens in which the annual egg production was raised from 145 to 235. This was done by selecting cocks that bred pullets which made good by producing an increased yield of eggs. Thus it was demonstrated that the male has a hand in the heredity of egg production, although it is the female that does the real work.

In similar fashion, bulls siring heifers that prove to be high milk-producers are selected for building up a herd of dairy cows. Bulls

cannot produce milk but they can sire heifers that do. In these cases, instead of predicting what the offspring will do by observing the parental performance, the offspring themselves are taken to show what their parents can do in producing desirable progeny. Mendelism has shown that selection of any kind, in order to be effective, must deal with genotypes rather than phenotypes, and that the material from which selection is made must be hybrid rather than pure in its composition if progress is to result.

Inbreeding and Cousin Marriage

Inbreeding in various degrees of consanguinity or blood relationship tends to produce uniformity, or purity, in the hereditary stream. Notwithstanding popular opinion to the contrary, inbreeding in itself is not harmful. It simply tends, in the case of hybrids, to bring recessive traits out into the open, and these are in many instances less desirable than dominant characters. Cousin marriage in highly hybridized human stocks is a potent way of unearthing "skeletons in the closet," for cousins, being of approximately the same hereditary make-up, are apt to carry concealed the *same recessive characters*, which thus have a Mendelian chance of getting together and becoming somatically visible. On the other hand, when people not closely related are mated together, their undesirable recessive traits, *being different in each parent*, are likely to remain concealed or covered up by corresponding dominants contributed by the other parent. For example, if Aa and Aa represent two similar related individuals of the same make-up so far as the characteristics A and a are concerned, there is one chance in four, according to the Mendelian monohybrid ratio, that the undesirable combination of aa will appear in the offspring. If, however, two unrelated individuals, Aa and Bb , carry undesirable gametes represented by the small letters a and b , there is only one dihybrid chance in sixteen that the individual showing the undesirable recessive combination $aabb$, with no concealing dominant to interfere, will appear, and there are only three additional chances each out of sixteen that either the aa or the bb recessive characteristic will come to light. (See checkerboard on page 451.)

In nature there are many instances where inbreeding is enforced. Wheat, and cereals generally, as well as the legumes to which Mendel's peas belong, are habitually self-fertilized, and this is even closer inbreeding than brother and sister mating, to say nothing of the pairing of cousins.

Outbreeding and Hybrid Vigor

Outbreeding, on the contrary, introduces variety and tends to cover up recessive defects by the introduction of new dominant characters, although it does not permanently eliminate the former.

In nature probably most animals and plants outbreed. Even hermaphroditic animals such as earthworms and snails, in which both sexes are included in one individual, usually mature their eggs and sperm at different times, as already noted, thus insuring outbreeding. The same thing is true to a large extent of the great array of plants in which both pollen grains and ovules are housed in the same flower.

One of the beneficial results of outbreeding is *hybrid vigor*, which usually accrues to the first generation of hybrids. This result may be accounted for as the summation of desirable dominant characters from the two diverse parents. The advantages gained by this type of cross, however, do not endure in successive generations, when inbreeding comes in with its leveling effects. The former confusion and uncertainty about the consequences of inbreeding, outbreeding, and hybrid vigor is straightened out when one goes behind the scenes with the insight made possible by Mendel's laws.

Asexual Propagation

Another practical way of maintaining desirable hereditary qualities, particularly in plants, when once they have been obtained, is by asexual propagation through slipping or grafting. This is the method employed in maintaining strains such as navel oranges, which produce no seeds, and also in plants which do produce seeds whose phenotypes are known desirable somatoplasms but whose genotypes are hidden in unknown problematical seeds. By this procedure of asexual propagation the desired combination is continued, without the introduction of any disturbing germinal modification from the outside. Many of Luther Burbank's famous plant "creations," such as the spineless cactus and the white blackberry, have been established and made available by this method.

The Germplasmal Method

The foregoing somatoplasma methods of approach in studying heredity, although to a remarkable degree successful, are at best only indirect. It is more and more apparent that the most hopeful line

of future advance is concerned with the direct analysis of the germ-plasm itself, that is, of the basic chemical materials (genes) out of which somatoplasms are derived. This has been made all the more possible within the last half century by the increased efficiency of greatly improved microscopes and microtomes, and through the development of staining technique by means of aniline dyes which render visible and differentiated microscopic details of structure that were formerly unseen.

Chromosomes

Every germ cell, as well as each of the somatic cells that are the building stones of the body, contains a *nucleus*, within which, at certain times in the life cycle of the cell, *chromosomes* may be seen. These structures stain more deeply with certain dyes than do other parts of the cell, thus becoming visible under the microscope.

It is doubtful that Mendel ever saw chromosomes, for it was not until the late seventies, after his scientific career was practically over, that the invention and development of aniline dyes made possible their discovery. Each pair of chromosomes has a characteristically different shape and size, whereby it is usually possible to distinguish them from every other pair. Chromosomes, moreover, retain their specific identity, in spite of the fact that they may change their form temporarily, or for a time disappear entirely from view. When germ cells undergo *maturation* to form their gametes as a preliminary to fertilization, the total number of chromosomes in each cell is reduced to one half. An entire pair is never normally eliminated, although this sometimes occurs under abnormal circumstances (*non-disjunction*). The result is that ordinarily there is left behind one complete outfit of all the chromosomes characteristic of the species, with their determinative genes, both in the mature egg and the mature sperm. As pointed out previously, fertilization restores *pairs* of chromosomes and then ever afterwards, by means of the meticulous machinery of mitosis, these pairs are handed on to all subsequent cells of the body that arise from the fertilized egg.

One of the evidences that chromosomes play an important part in heredity lies in the fact that they are the only parts of the germ cells in which the two sexes contribute equally to the formation of the fertilized egg in animals, or ovule in plants, that initiates a new individual. It is common observation that each parent in the long run is equally responsible for hereditary traits in the offspring, and

this agrees in general with the fact of equal contributions to the following generation of chromosomes from each parent. It has been repeatedly shown by experiment, as, for example, with the eggs of sea-urchins, that when more than one sperm enters and fertilizes an egg, thus involving the presence of an atypical number of chromosomes, the resulting larvae are monstrous, or at least abnormal, and do not long survive. Evidently this is a case of too much father! The conviction of the responsibility of chromosomes in heredity is further strengthened by a very large number of remarkably ingenious investigations made in the last twenty years, centering about the *occasional abnormal behavior* of chromosomes during the maturation divisions, particularly with the much-studied banana-fly *Drosophila*, maize, and the jimson-weed *Datura*. It is not possible in this limited summary to do more than to call attention to this brilliant and complicated work, which goes far in confirming the importance of chromosomes in heredity. It is earnestly hoped, nevertheless, that the reader may eventually have the opportunity to explore this fairyland of fact. Although it involves a somewhat discouraging array of strange technical terms, such as *non-disjunction*, *translocation*, *coincidence*, *inversion*, *duplication*, *deficiency*, *deletion*, *interference*, and *ploidy*, it turns out that the terms used are not at all formidable upon closer acquaintance.

Genes

Although the chromosomes of the male and female germ cells unite to build the "imponderably small" bridge over which the hereditary load passes from one generation to another, they are not in themselves the actual units of heredity. These ultimate bearers of inheritance, which are borne by the chromosomes, are known as *genes*, a name given them by the Danish botanist Johannsen (1859-1927). Dr. W. E. Castle has defined a gene as "the smallest part of chromatin capable of varying by itself." In other words, genes are the ultimate invisible hereditary units and as such form the essential subject matter of genetics.

That no one has ever surely seen genes under the microscope does not lessen the fact of their reality. Like the atoms of the chemist and the electrons of the physicist, of whose reality there is no doubt, they are too small to be seen by any means at present at our disposal. We know next to nothing about the structure and chemical composition of these ultimate hereditary units; nevertheless, we already know

a good deal about their behavior, although the scholarly attack upon the gene in the light of what is sure to follow can be said to have hardly begun.

It is plain that there are many more distinguishable traits and characters present in an organism than there are chromosomes. In *Drosophila*, for example, which has only four pairs of chromosomes to a cell, over five hundred hereditary differences have been accurately identified. Consequently, many determining genes must be located in each pair of chromosomes. What has been found to be true of *Drosophila* in this respect, is undoubtedly true of other organisms. So much of our knowledge of genes in general has been acquired by investigations upon the ubiquitous banana-fly that genetics stands in some danger of becoming *Drosophiletics*. These tiny flies, that have never even heard of birth control, lend themselves very favorably to the study of genes. Within a month a single pair can become grandparents of so many grandchildren that it is difficult to keep track of them. Millions have actually been experimentally bred and critically examined *one by one* by different workers within the past three decades since their scientific usefulness has been discovered. They even gained the Nobel prize award (1934), with the aid of Dr. Thomas Hunt Morgan and his associates.

It has not only been possible for the investigators of *Drosophila* to determine more than five hundred determining genes in these flies, but also even to locate these several genes definitely in particular pairs of chromosomes, and to arrange them with reference to each other at definite distances apart within a single chromosome. All that has been learned by the followers of Mendel about the interaction of what are termed "factors" applies to the invisible genes. For example, it is not likely that single genes, any more than single factors, "determine" single somatic traits or characteristics. Rather the genes must work together to bring about visible results, since "genic balance" is essential to somatic success.

Linkage and Crossing-over

Although there is, as Mendel demonstrated, *independent assortment* between different chromosomes during the formation of the gametes, the genes that are located in *any single chromosome* tend to hang together in succeeding generations and not to become separated from each other. This is called *linkage*. By means of it, whole blocks of genes may act together as a unit in heredity.

Mendel did not hit upon linkage, because it fortunately so happened that the determiners of the seven characters (page 444) with which he dealt were each located in separate chromosomes, of which there are known to be seven pairs in garden peas. This was a happy accident, for if Mendel had chanced upon genes linked together in a single chromosome, he might never have been able to establish the law of independent assortment, which is so essential in determining the Mendelian ratios.

In mitosis it sometimes happens, however, as shown by the subsequent breeding results, that chromosomes emerge which contain a different combination and arrangement of genes than that in the originals from which they came. In other words, linkage is broken up. The way this comes about is as follows. During the process of the preparation of the germ cells for sexual union (*meiosis*), as has been repeatedly observed, the maternal and paternal chromosomes in each pair of egg or sperm come to lie close together side by side. They may even twist around each other. This intimate contact of homologous chromosomes from the two parents is called *synapsis*. It will be recalled how later the *still entire chromosomes* separate or unwind from their mates and migrate to opposite poles of the germ cell, during the unique *reduction division*, thus forming two new cells each containing but half the normal number of chromosomes in each cell. This means that either the maternal or the paternal chromosome of each pair is missing in the resulting daughter cells, while the end result of ordinary mitosis, or cell division, is the production of two new cells, each with a complete equipment of chromosome *pairs* representing the maternal and paternal contributions.

After synapsis, the two chromosomes in each pair may separate and go their different ways with all their genes linked together exactly as they were before intimate contact with each other, or during synapsis they may stick temporarily together and then later break into fragments and become reassembled in a new relationship, with a part of a paternal chromosome attached the supplementary part of a maternal chromosome. When such an interruption of linkage occurs it is termed *crossing-over*. It is as though, following an ardent embrace, Jack's head should be found perched on Jill's shoulders, and in exchange, Jill's head should turn up on Jack's shoulders. That this extraordinary kind of performance actually does happen with the chromosomes has been amply demonstrated over and over by observing the ratios in which the offspring appear following a dihybrid cross.

An illustrative case may serve to make both linkage and crossing-over plainer. In corn, colored kernel (C) is dominant over colorless kernel (c), and plump starchy grains (S) are dominant over wrinkled

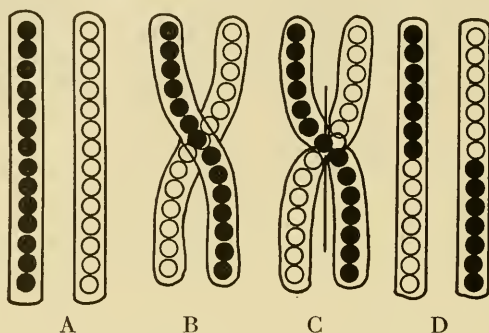


Diagram of the steps in crossing-over. *A*, an allelomorphic pair of chromosomes, with genes represented as solid or open circles; *B*, synapsis, or the contact of homologous chromosomes; *C*, breakage of chromosomes at the point of contact; *D*, reassembly of chromosome fragments, resulting in a cross-over of genes, making a new combination.

sugary grains (s). Thus, when pure colored-starchy corn ($CCSS$) is crossed with pure colorless-wrinkled corn ($ccss$), the resulting hybrid will be colored-starchy like the dominant parent in appearance but with the genotypic formula of $CcSs$. When in turn these hybrids are back-crossed with the recessive parent ($ccss$), in order to reveal the different kinds of offspring which they are capable of producing, the expected result, *if there is independent assortment*, would be the ratio of $1CS:1Cs:1cS:1cs$, as shown below.

	HYBRID GAMETES			
	CS	Cs	cS	cs
Recessive gametes cs	$CScs$	$Cscs$	$cScs$	$ccss$

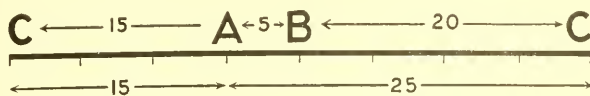
In an actual experiment, however, when the hybrid was back-crossed to the recessive parent, the offspring were phenotypically 4032 CS : 149 Cs : 152 cS : 4035 cs . This is approximately the ratio of 48:2:2:48, instead of the expected 1:1:1:1. The explanation of this result is that out of a total of 8368 cases there were 8067 instances in which the characters CS and cs , that entered into the

hybrid combination together, stayed together in *linkage*, while in the remaining 301 cases out of 8368, *crossing-over* occurred between the colored (*C*) and the starchy (*S*) genes derived originally from one grandparent, with the corresponding colorless (*c*) and wrinkled (*s*) genes furnished by the other grandparent. These cross-overs were a new combination in corn, namely, colored-wrinkled (*Cs*), and colorless-starchy (*cS*).

Chromosome Maps

By experiment, particularly with *Drosophila*, which lends itself especially to this kind of investigation, varying percentages of crossing-over between different pairs of genes located in the same pair of chromosomes have been determined. This method of taking advantage of the occurrence of crossing-over has led to the determination of the *distance between individual genes* in particular chromosomes, depending upon the principle that the nearer together two pairs of genes are, the more likely they are to remain linked when the chromosomes twist about one another and subsequently break and rejoin, while the farther apart they are, the more likely they are to shift from one chromosome to the other during synapsis.

For example, if the percentage of crossing-over, as shown by the results of breeding, between the hypothetical genes *Aa* and *Bb*, is *five*, and that between *Bb* and *Cc* is *twenty*, then the cross-overs between *Aa* and *Cc* ought to be *twenty-five* ($5 + 20$) if the order of the genes in the chromosomes is *A-B-C*, or *fifteen* ($20 - 5$) if the order of arrange-

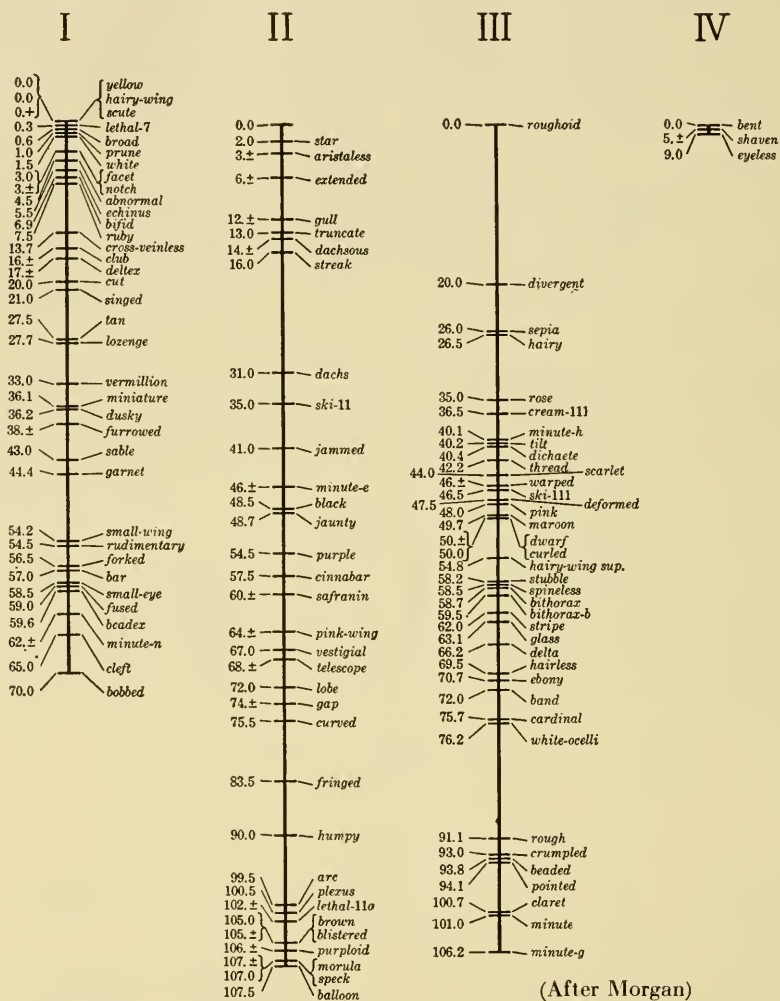


The determination of the order of genes on a chromosome.

ment is *C-A-B*. This kind of confirmation has been repeatedly verified in actual breeding experiments.

By an extension of this technique it has been possible to construct *chromosome maps*, in which the location of the different invisible genes in the various chromosomes can be determined with astonishing accuracy. Such a map of the four different chromosomes in *Drosophila*, as far as it had been completed in 1926, when Morgan published "The Theory of the Gene," is shown on page 462. Today the chromosome map of *Drosophila*, like a recent map of the world as com-

pared with one of Marco Polo's day, shows many new additions, thanks to the patient and tireless labors of the small army of *Drosophila* philologists.



"When it is remembered that *Drosophila* is a very tiny fly; that paired reproductive organs occupy only a small part within its abdomen; that each of these reproductive organs in the male is made up of several tubules; that within these tubules may eventually be found the sperm cells with plenty of room in which to move about; that within each sperm cell is a nucleus;

that after half the contents of the nucleus has been disposed of there remains four chromosomes; that within each chromosome there are, beyond the range of vision, hundreds of genes; and that it is possible within a single chromosome to determine not only the relative arrangement of the many genes, but also to find out the relative distance between any two of these genes, it will be realized that the analysis of the germplasm has gone a long way.”¹

The Rôle of the Cytoplasm

In spite of the demonstrated importance of the chromosomes and their genes in the mechanism of heredity, they are not the whole story. There is the *cytoplasm* to be reckoned with, particularly in the egg. In no cell can either the nucleus or the cytoplasm lead an independent existence. Each depends upon the other. Hence, while the undoubted significance of the chromosomes is being emphasized, it is well to remember also the indispensable cytoplasm. Is there such a thing as *cytoplasmic inheritance*, in addition to that of the genes?

In answer to this question it is necessary in the first place to distinguish the part that cytoplasm plays in development as well as its possible function in hereditary transmission.

The nuclear membrane separates the chromosomes from the surrounding cytoplasm during the resting stage of every cell cycle, resulting in some degree of temporary independence. However, every time mitosis is repeated this protective membrane vanishes for the time being, leaving the chromosomes directly exposed to the cytoplasm. Here, then, is furnished an opportunity for exchange of materials between chromosomes and cytoplasm, and this exchange does undoubtedly occur. During mitosis, it will be remembered, each chromosome splits lengthwise, and the half chromosomes thus formed, mingling freely with the cytoplasm, migrate to their respective poles. Meanwhile they are restored to their original dimensions by the intake of material from the cytoplasm itself. Thus a part of the cytoplasm of the cell becomes made over into chromosomal material.

In the long series of successful mitoses by means of which the zygote eventually becomes an adult individual, the chromosomes in each newly formed cell still maintain their original genetic make-up as to form and numbers of pairs. The cytoplasm of these various cells, on the other hand, undergoes transformation to constitute the different

¹ From Walter, H. E., *Genetics*. By permission of The Macmillan Company, publishers.

tissues of the body. In other words, while there is accomplished an equal distribution of chromosomes, an *unequal* distribution and elaboration of the cytoplasm takes place. It is plain, therefore, that in this process the genes not only take in material to be elaborated from the cytoplasm, but that in turn something must go out from them to bring about the differentiation of the surrounding cytoplasm. That there is a chemical difference between what is in the chromosomes and what is outside of them is proven by the differential way in which these substances respond to certain stains. Apparently there is carried on from generation to generation throughout life an elaborate and extensive performance of "give and take" between the germplasmal chromosomes and the somatoplasmal cytoplasm of the cells. Dr. H. S. Jennings states the matter in the following words:

"This process of changing the cytoplasm by the action of the genes is the fundamental thing in development. The genes repeat this process over and over again, taking in cytoplasm, modifying it, giving it off in changed condition, and leaving the genes themselves unaltered."¹

In the light of the intimate relationship between genes and cytoplasm, and recognizing the dominant part taken by it in developmental processes, can we assign any truly *hereditary* rôle to the cytoplasm itself, except as it is first taken in and made a part of the chromosome complex?

It is common knowledge that apple blossoms, when fertilized with foreign pollen, produce only apples like the maternal parent because the apple itself is merely an elaboration of the maternal tissue of the ovary, determined in its character before the ovule in the ovary is fertilized. Seeds of such apples, however, grow into trees that produce fruit showing paternal as well as maternal characters. This sort of "maternal inheritance" suggests the presence of some hereditary factor outside the genes that keeps an apple a sweet apple, for instance, although its blossom is fertilized by pollen from a sour apple tree. It is only necessary, however, to remember that the cytoplasm of the sweet apple is already determined by the germinal contributions of the preceding generation, both maternal and paternal, rather than by the fertilizing pollen in the present case, in order to find a satisfactory explanation that does not involve cytoplasmic determination.

¹ From Jennings, H. S., *Genetics*, p. 233. By permission of W. W. Norton & Company, publishers.

In practically all groups of plants there are certain structures embedded in the cytoplasm called plastids, which are centers of metabolic activity. They are composed of packets of various materials essential to plant life, such as starch grains, chlorophyll, oil droplets, and the like, having a definite chemical composition and easily visible under the microscope. It is generally agreed that plastids are derived from preceding plastids, quite as chromosomes are from preceding chromosomes, and that they are not formed anew in each cell. Unlike chromosomes, however, they do not undergo orderly mitosis when they divide, thus securing in daughter plastids an accurate halving of material as in the case of chromosomes and genes, nor do they always follow the Mendelian laws in their redistribution. A case in which the chromosomes and genes do not apparently play their usual equal parts, but in which it looks as if the inheritance is through self-perpetuating plastids in the female cytoplasm and never through the male gametes, is found in plants with variegated or striped leaves. In these plants, the cells with plastids carrying chlorophyll (*chloroplasts*) determine the green areas in the leaf, while cells with plastids that lack the chlorophyll (*leucoplasts*) account for the white areas. Branches and flower buds occur with either chloroplasts or leucoplasts. When crosses are made between flowers borne upon a green branch, and those from a white branch of such variegated plants, the resulting offspring are white or green according to the kind of plastids present in the *maternal parental branch*, irrespective of the kind of pollen employed. The *grand-parental genes* determine the character of the maternal plastids, which in turn cause the new branch or plant to be white or green.

Current opinion about the whole matter is summarized in the statement of Dr. E. M. East to the effect that "though the nucleus and cytoplasm co-operate in *development*, the only ascertained agent of *heredity* is the nucleus." What the future may disclose still remains a question unanswered, but at present it appears that "cytoplasmic inheritance" is unproven.

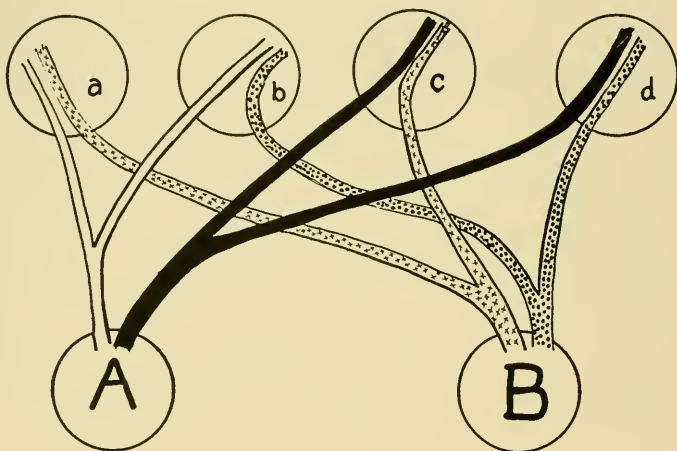
Sex in Heredity

While it is quite possible for one generation to arise from another by various asexual methods, yet it is evident that the whole mechanism of heredity has been revolutionized by the rise of sex.

As previously pointed out in the section on "The Usefulness of Hybrids" (page 441), in the study of heredity so long as level uniformity

characterizes the succession of generations, there is no way by which the laws of inheritance may be detected. Distinctive alternative characters must be introduced from *unlike* parents and combined in various ways in order to make the manner of inheritance in the progeny recognizable. Transitory environmental variations, since they play no part in inheritance, only cloud the picture. It is germ-plasmal variations alone that can be of service in inheritance, and such variations are provided in double measure by the device of sexual reproduction. Thus sex is not only the major means by which inheritance is effected but it also furnishes the key that unlocks the mystery of how evolution is brought about.

The way in which sexual recombination can change the flow of germplasm from one generation to another is suggested in the figure,



Two different biparental streams of germplasm, *A* and *B*, may form four new different biparental streams of germplasm, *a*, *b*, *c*, and *d*, in the next generation.

which reduces the matter to terms so simple that it is consequently entirely inadequate to represent the actual complexity and possible rearrangement accompanying sexual reproduction.

Although Mother Nature's children, that is, plants, animals, and even mankind, have successfully utilized the mechanism of sex for an incomprehensible span of time, it is only in recent years that man has come to understand, with anything like scientific accuracy, the way in which it works.

In the eighteenth century, the "ovists" held that the egg was the all-important factor, and that the sperm simply served to start the

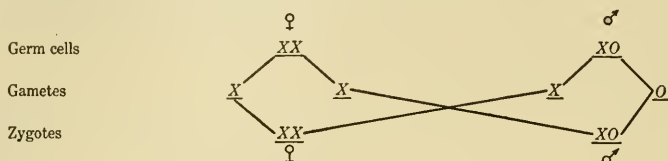
egg on its developmental way. An opposing school of "spermists" maintained that the egg was only useful as a means of food storage for the essential sperm. Notwithstanding the fact that the ancient Assyrians were well aware that date palms would not mature fruit unless pollen from male trees was dusted on the blossoms of the female trees, it was less than a century ago that it was finally established by Leuckhart (1822-1898) that both egg and sperm are homologous partners in heredity.

It was not until the beginning of the present century, after Mendel's laws had been re-established and chromosomes had been discovered, that sex was recognized as a hereditary trait in itself, dependent principally upon genes. That other factors besides genes may contribute to the determination of sex is no doubt true. For example, Dr. Oscar Riddle, of the Carnegie Institution of Washington, has advanced a well-grounded theory of the *metabolic determination of sex*, based upon exhaustive experiments extending over many years, in breeding doves at Cold Spring Harbor, Long Island. Other investigators have emphasized the modifying influence of the external environment, and of the internal hormones, but no one denies the action of the genes as the primary effective factor in sex determination.

The theory most generally accepted today to account for the approximate equality of the sexes in the offspring of any species is that of Correns, who postulated that the gametes of one parent are of two kinds, male-producing and female-producing, while the gametes of the other parent are alike so far as sex determination is concerned. This idea has been amply substantiated by the discovery in many forms of plants and animals of what has subsequently been designated as *sex chromosomes*.

As has been repeatedly emphasized, chromosomes occur in homologous pairs, one member from each parent. McClung in 1902, discovered that in the germ cells of the male locust, *Xiphidium fasciatum*, there occurred an odd chromosome without a mate while in the female immature germ cells every chromosome was supplied with a corresponding mate. Consequently, this being the case, when the members of the chromosome pairs, following synapsis, separate to form the gametes, the odd chromosome joins one group of daughter chromosomes, leaving the other group one chromosome short. The former sort of gametes, carrying the odd chromosome, upon union with a normal female gamete having a full quota of chromosomes,

forms a zygote that will produce a female, while the latter sort without the odd chromosome, when uniting with the normal female gamete, produces a zygote that is destined to become a male. Thus, if XX represents the sex chromosomes of the female, and XO those of the male, the result is diagrammatically as follows:



In many instances it has been observed that the formula XY , instead of XO , represents the male sex chromosome pair, while the female remains XX . That is, instead of an odd unpaired sex chromosome, there is a *mismatched* pair. The accompanying figure, showing the chromosomes in *Drosophila*, serves as an example of such a case. It will be seen in this figure that in the male there are present three pairs of chromosomes in which the mates are alike, but that one chromosome of the fourth pair is rodlike, while its mate, the Y -chromosome, has a bent tip. By substituting Y for the O in the preceding diagram, the same explanation for the equality in number of the sexes among the offspring is reached, as in the case of McClung's locusts. In both of these examples it is the number of X -chromosomes present,



The four pairs of chromosomes in *Drosophila melanogaster*. (After Morgan.)

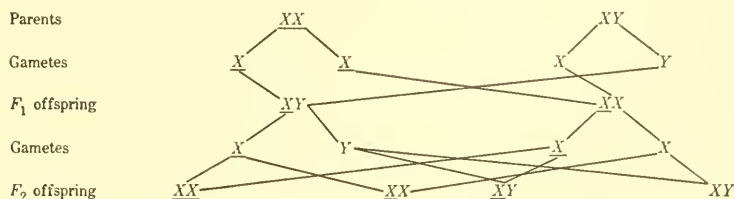
that is, one or two, that determines the sex of the offspring.

Other variations of this fundamental idea have been found in the copious investigations which have been made on the heredity of sex, but all agree with Correns' original interpretation of unlike sex gametes in one parent and like gametes in the other.

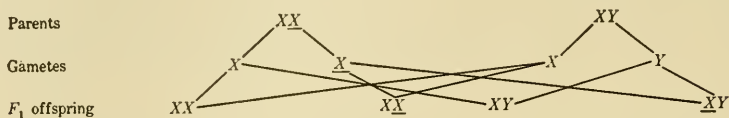
The great majority of plants and animals that have been examined show that the male ordinarily is the sex that produces two kinds of sex-determining gametes. Birds, butterflies, and moths form an exception to this general rule, for in them all the sperm gametes are of one kind, while two kinds of mature eggs, male-producing and female-producing, occur. The result of approximate equality of the sexes in the progeny, however, is the same as in the former instances.

In mankind there are twenty-four pairs of chromosomes, of which twenty-three pairs, common to both sexes, are called *autosomes*, and to these is added one pair of sex chromosomes, designated XY in the male and XX in the female. A curious fact about Y -chromosomes in general is that, with few exceptions, breeding experiments prove them to be devoid of genes. They play a dummy hand. Thus the Y -chromosome exerts the same non-contributory rôle in heredity as the O element does in the XO combination. The X -chromosome, on the other hand, not only plays a part in sex determination, but it also harbors additional genes that control the appearance of other traits and characters. These are called *sex-linked* traits. Their existence is demonstrated in the male because there is nothing in the Y -chromosome mate to conceal them.

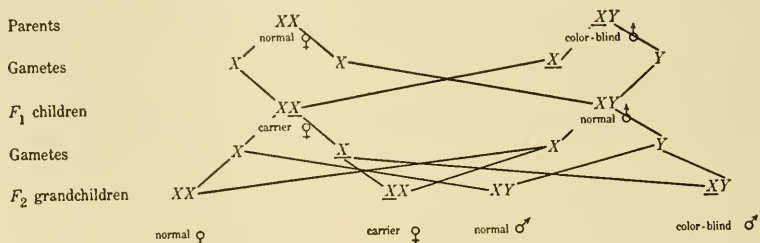
This point may be made clear by citing Morgan's now famous case of the white-eyed *Drosophila*. Many years ago in one of his cultures of normal red-eyed flies, there appeared a single white-eyed male mutant individual. The conjunction of Professor Morgan's seeing eye with the white eye of this particular tiny fly marks an event in the history of genetics comparable to what happened to the science of physics when the falling apple and Sir Isaac Newton's head came together. In both cases an exceptional brain was fortunately stimulated, with far-reaching benefits to science. When Morgan's unique white-eyed male fly was mated with a normal red-eyed female, all the offspring were red-eyed, thus showing the dominance of the red-eyed character over white-eye. When these red-eyed hybrids were mated together, the expected Mendelian ratio of three reds to one white resulted, *but all the males were white-eyed*. Omitting the autosomes and representing only the sex chromosomes, the matter may be diagrammed as follows. (The underscored X indicates that red-eye color is linked with the sex chromosome. The absence of underscoring means white-eye.)



In order to obtain a white-eyed female, it was necessary to mate a white-eyed male to a *hybrid* red-eyed female, which works out as follows:



In this type of sex-linked inheritance, the paternal character may be transferred directly in 50 per cent of the cases from father to son and from mother to daughter. There is another type of sex-linkage, as exemplified by some kinds of color-blindness in man, in which the inheritance is never direct from father to son and from mother to daughter, but indirect, or zigzag, as from father through daughter to grandson. This is called *criss-cross inheritance*. Thus, when a female, normal for color-blindness, is mated with a color-blind male, the trait skips a generation before it reappears.



It will be seen that in addition to regular Mendelian inheritance, which has to do with the genes located in the various autosomes and which results in the typical 3:1 ratio when the hybrids are bred together, there are two other types of inheritance, involving the sex chromosomes. One of these is the *direct type* in which the character may be handed on from father to son or from mother to daughter, and the other is the *indirect type* of criss-cross inheritance in which the father cannot give the character to his son, but may pass it along to his grandson by way of his daughter.

In drawing this section to a close, it is worth while to quote the opinion of the eminent English geneticist, C. C. Hurst, who says, "Perhaps there is nothing which has helped the study of genetics more than the existence of sex." It would take us too far afield to follow out the enticing vistas of heredity opened up by the phenomenon of sex. Some of the many aspects of heredity which might

be considered in this connection are suggested by such terms as sex hormones, sex determination, sex reversal, parthenogenesis, hermaphroditism, gynandromorphs, gonad transplantation, sterility, freemartins, and identical twins. In order to go on, the interested student must have recourse to books and source material devoted entirely to genetics. Even with such aids much that is new and illuminating in this rapidly developing science will be found wanting.

SUGGESTED READINGS

Castle, W. E., *Genetics and Eugenics*, 3rd ed., Harvard University Press, 1924.

An authoritative summary by a pioneer in genetics.

Crew, F. A. E., *Animal Genetics*, Edinburgh, 1925.

The way a brilliant Scotchman sees heredity.

Dunn, L. C., *Heredity and Variation*, The University Society, 1934.

Brief and very readable.

Jennings, H. S., *Genetics*, W. W. Norton & Co., 1935.

Particular emphasis upon the chromosomal aspect.

Morgan, T. H., *The Theory of the Gene*, Yale University Press, 1926.

The statement of a Nobel prize winner.

Schwesinger, G. C., *Heredity and Environment*, The Macmillan Co., 1934.

Emphasis upon the genesis of psychological characteristics.

Sinnott, E. W., and Dunn, L. C., *Principles of Genetics*, 2nd ed., McGraw-Hill Book Co., 1932.

A widely used text.

Snyder, L. H., *The Principles of Heredity*, D. C. Heath & Co., 1935.

A very excellent up-to-date book.

Walter, H. E., *Genetics*, 3rd ed., The Macmillan Co., 1930.

An elementary presentation.

Wilson, E. B., *The Cell in Development and Heredity*, The Macmillan Co., 1925.

A masterly storehouse of reliable information.

THE CHANGING WORLD

XXI

TIME SPENT (PALEONTOLOGY)

PREVIEW. The stretch of time · Measures of time · Kinds of fossils · Fossils as time markers · The testimony of extinct types · The rôle of paleontology · Suggested readings.

PREVIEW

There are two things with which living creatures are inseparably involved and from which there is no escape, *space* and *time*.

Although everyone has a working idea of what is meant by these two common words and uses them freely and constantly in all sorts of connections, it is somewhat surprising how difficult it is to define them satisfactorily without making use of other words that require definition as well. Try it! Just what *is* time? Do not resort to the dictionary until you are willing to give up. You will probably find the dictionary disappointing. Is time, perhaps, that particular bit of eternity to which we can set limits? If so, what is eternity?

There are two sciences in this connection that are profitable to explore, if only to enlarge our intellectual sky lines. The first and older science is *Astronomy*, which serves to expand our ideas of space, and of which man alone can have any inkling. The second is *Paleontology*. Although this has been developed more recently, it is nevertheless concerned with very old things. One benefit to be gained from the study of paleontology is that it stretches, and makes more spacious, our concept of time.

It is not the purpose of this section to present an outline of paleontology, but simply to consider very briefly the *relation between time and living things*. The rôle of living things with reference to space has already been touched upon in unit II under the title, "The Biological Conquest of the World."

The Stretch of Time

Whatever time is, the geologist has plenty of convincing evidence that an enormous amount of it already has been spent upon this earth since it became the earth, for time was passing, "with no vestige of a

beginning and no prospect of an end," even before the "everlasting hills" were born. The geological evidences of the passage of time are plain and unmistakable to everyone.

A visit to the Grand Canyon of the Colorado, for example, and an inspection of the gigantic stone book there revealed, with its leaves of stratified rock piled one upon another, must impress even the most

flippant traveler with the record of time spent that is there displayed. Stratified rocks made out of sediment such as those which form the walls of that stupendous gorge were built up first somewhat slowly through the erosion of land masses, then the sediment was collected and borne away by flowing streams and finally deposited bit by bit in horizontal beds under water. These sediments were subsequently compressed, cemented, and hardened into layers of stone, varying in thickness.



U. S. Geological Survey

Erosion in the Grand Canyon of Colorado has laid bare stratifications of soil formation deposited in centuries past.

Sooner or later there might follow the gradual shifting of the levels of land and water, possibly caused by the aging and consequent wrinkling on a large scale of the earth's crust. At any rate, whatever the cause, there has resulted an eventual submergence here and there of what was once land, as well as a slow up-thrust of the neighboring ocean bed to form newly emerged land.

Meanwhile rain fell, not continuously in delugelike floods, but from time to time just as it does at present, with considerable intervals between the rainy spells. In fact, there is every reason to believe that all the processes leading to the formation of sedimentary rocks

in the past were gradual and time consuming, exactly as they are seen to be before our very eyes today.

Such repeated rainfalls drain down the slopes of the newly emerged land, and, after countless contributions from lesser streams, combine into rivers which cut slowly into the elevated accumulations of sedimentary rock and wear it away. Thus, in the course of long eons of time, a river with its abrasive sediment scours out and fashions a gorge.

In the case of the Grand Canyon the rushing Colorado River, now down a mile deep from the rim of the gorge, is still grinding away unceasingly at its uncompleted task of recording spent time. What a majestic open diary of the passage of time!

Measures of Time

The biologist finds it not only convenient but indispensable to establish some sort of foot-rule by means of which the continuous and incomprehensible past may be divided into understandable portions. To this end, the stratified or sedimentary rocks of the geologist prove to be of the greatest use. Even so, only through much persistent study by experts has anything like a satisfactory time-scale been evolved.

Sedimentary rocks, for example, sandstones, limestones, and shales, do not envelop the entire earth in continuous layers in the way that an onion is made up. They occur only in patches here and there, where once was water in which they could be deposited from the surrounding land masses. However, when the various patches of sedimentary rocks the world over are examined and compared, it is quite possible to piece them together, like a jig-saw puzzle, into a total column of layers one above the other.

For purposes of identification and description, the time consumed in the formation of this column may be divided into *eras* and subdivided into *periods*. While the opinion of experts may differ with respect to the limits and details of these arbitrary divisions of past time, there is universal agreement as to their orderly sequence. Such a time-scale of eras and periods is given on the following page.

In this time-scale stratified rocks can be employed as a standard of estimation for only approximately the last half of known time, *i.e.*, 45 per cent. The rocks of the Proterozoic and Archeozoic eras that characterize the older approximate half, *i.e.*, 55 per cent of the time-scale, are either of the original fire-fused sort which has never been

GEOLOGICAL TIME-SCALE (Lull)

ERAS	PERIODS	ESTIMATED PERCENTAGE OF ALL KNOWN TIME	
Psychozoic	Recent (Post-glacial)		
Cenozoic	Pleistocene (Glacial)	4%	
	Pliocene		
	Miocene		
	Oligocene		
	Eocene		
Mesozoic	Cretaceous	11%	45%
	Jurassic		
	Triassic		
Paleozoic	Permian (Glacial)	30%	
	Carboniferous		
	Devonian		
	Silurian		
	Ordovician		
	Cambrian		
Proterozoic		25%	55%
Archeozoic		30%	

subjected to erosion and stratification, or those which, even if they may once have been sedimentary, have lost their stratified character, due to crushing pressure or to transforming association with volcanic forces. Marble, for example, laid down originally in layers following the disintegration of calcareous skeletons, or by the deposition of dead shells of myriads of microscopic marine organisms, is metamorphosed sedimentary limestone, while quartzite and gneiss are rocks that, by the action of heat and pressure, have been made over out of sandstone, which was also once stratified.

Sedimentary biology, or the horizontal arrangement of fossil remains in sedimentary rocks, practically begins with the Paleozoic era, although there are shadowy evidences, such as the graphite traces of primitive seaweeds, showing that life occurred as far back as the Archeozoic era. In the rocks of the Proterozoic era have also been found scanty traces of calcareous algae, primitive sponges, and shells of radiolarians, but most of the remains of life during this enormous expanse of time have been obliterated. Only a part of the Proterozoic, and some of the Paleozoic, era are represented in the famous walls of the Grand Canyon of the Colorado.

The Pleistocene period, in which modern man finally made his appearance, and which probably does not include more than 50,000 or 100,000 years, is such an insignificant fragment of the whole that it is scarcely worth while to attempt to include it in a percentage column of known time.

Kinds of Fossils

A fossil is an indication of past life, not of recent past life but of something that lived so long ago that ordinarily it would be forgotten and disregarded entirely, except for the interest of the curious inquiring paleontologist.

Fossils are of many kinds. They may be the *actual remains* of organisms preserved indefinitely from decay, as, for example, mixed-up bones of struggling animals caught in the ancient asphalt pits at Rancho La Brea in California; insects imprisoned in transparent



Courtesy of Los Angeles Museum

Skulls and bones of bison, horse, and dire wolf are recognizable in this mass of fossil bones ready for removal from one of the tar pits at Rancho La Brea, California.

amber, which is hardened Oligocene pitch; or mammoths frozen centuries ago in arctic mud and ice, with no opportunity since then



Mammoths preserved in arctic ice.

to thaw out, of which at least a score of authentic instances are known.

Petrifications of bone or shell or wood are another kind of fossils, formed by the filtration of dissolved minerals into spaces left after the decay of the original organic matter. In such fossils the inorganic part has resisted disintegration

long enough to serve as a matrix or a mold, and thus to preserve the original shape. Sometimes the mineral replacement of minute parts may be so gradual and complete that the bone or shell or tree-trunk is said to be "turned to stone," often with histological details faithfully retained. *Limestone* is often composed of innumerable shells of minute organisms, such as foraminifera and the skeletons of corals that extract from the water the necessary calcareous materials.

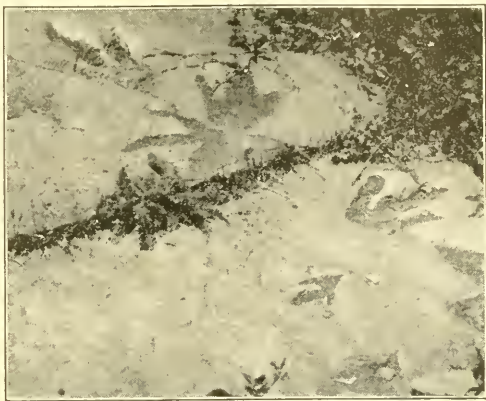
Still other types of fossils are *casts* and *molds* in which the organisms or parts of them remain undestroyed long enough to permit the taking of a permanent death mask of some kind, which is then all that is finally preserved. Some beautiful examples, which may reproduce in great detail the character of the original, are impressions of ferns and leaves, or of insect wings, occasionally to be found when shale or slate rock is split open.

Under favorable circumstances, tracks and trails left by



A Paleozoic fernlike plant.

animals may be preserved, showing that the animal in question was once a going concern. Just as rabbit tracks in the snow register the fact that a rabbit has passed that way, so the many stone footprints which Professor Hitchcock of Amherst College originally discovered up and down the Connecticut Valley are dinosaur autographs, signed in the great stone book, that record who were once travelers there.



Milton R. Weed

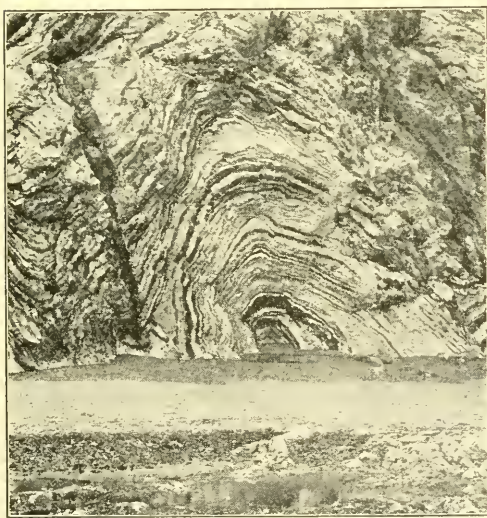
Dinosaur footprints in Connecticut.

Particularly curious fossils are the so-called *coprolites*, which are hardened feces of animals. These, in some instances, by their twisted form, give a hint as to the structure of the vanished soft parts of the posterior part of the intestine, which were able to shape excreta in such a fashion. Some coprolites, furthermore, even enable the

paleontologist to determine the bill-of-fare of an animal that lived perhaps a million years ago.

Finally, *coal* and *oil* deposits, wherever found in nature, mark the place and time of former vegetative life.

In all these cases what we call a fossil is a truthful and undeniable witness of the former existence of a living thing. They are not to be confused with *artifacts* which are structures fashioned by the hand of man.



U. S. Geological Survey

Folded beds of limestone on the south coast of Alaska.

Fossils as Time Markers

Just as the inclusion of contemporary documents of various sorts within the corner stone of a building, or the carving of a date over the door, indicates the time when the building was erected, so the presence of fossils, found embedded within a particular layer of sedimentary rock, serves to fix the approximate time when the sedimentation occurred.

Since fossils succeed each other over long reaches of time in a cumulative series, they aid in establishing the date when a particular layer of the earth's crust was formed, as was first pointed out by William Smith (1769-1839), who succeeded in homologizing certain scattered rock formations in England by means of typical key fossils found in them. Moreover, the kind of stratified rock in which fossils are found in turn helps to determine when the organisms which resulted in fossils lived. Thus, the confirmation works both ways. This is not as much of a vicious circle as it may seem to be, for the progressiveness, or upward evolution, of organic forms is not taken advantage of in estimating the relative ages of different strata until after the strata themselves have been surely arrayed, by painstaking observation and interpretation, in their unmistakable natural order of occurrence.

The Testimony of Extinct Types

A ruined castle on the Rhine, with broken battlements and tumbling towers, is a mute witness to many years employed first in building, followed by a probably extended period of occupation, and by a final period of gradual decay and abandonment. It is quite unlike the flimsy tent of the camper, which is quickly put up at night and taken down in the morning. The castle stands for the lapse of time. The tent does not. The same story of the flight of time is told more emphatically by fossil animals and plants.

While there have been innumerable individual animals and plants that have lived and died in the past, usually without leaving any trace of their former existence, there are also whole groups of organisms, that is, species, genera, families, orders, and even classes, which have likewise become entirely extinct, and are now known to have existed only because of the occasionally fossilized remains of their representatives. To have developed these extensive groups by any process of evolution, and then to allow time enough for the bringing about of

their gradual downfall and elimination, naturally calls for more than the work of a day.

When one visits a museum, like the American Museum of Natural History in New York City, and there encounters the unbelievable genuine framework of some towering dinosaur, he is compelled to admit that it must have taken a great deal of time to evolve such a creature by any possible process of slow successive adaptations.



Comparative sizes of man and dinosaur.

Moreover, not one kind of dinosaur alone but many diverse kinds, which have taken time enough to branch off from the original stock, whatever that was, have, without the least shadow of doubt, also lived and died. Probably the slow processes that have led up to such bizarre manifestations of former life in many cases ran concurrently, like jail sentences, but even so, enormous quantities of time must have been demanded for the accomplishment of these known results. It does not seem likely that a sane and reasonable Creator ever made one of these dinosaurs *de novo*, "out of whole cloth." They bear every mark of having been repeatedly cut over and reassembled out of preceding garments. There is no evidence, moreover, that dinosaurs came to a sudden catastrophic end all at once. It took long periods of additional time finally to undo the gigantic task, and to bring about the wreckage and gradual extinction of these elaborate creatures.

The age-long episode of the rise and fall of the dinosaur dynasty, for example, which endured for some millions of years, has been

repeated over and over again in the case of other animal and plant groups. Thus, not only is the fact of the existence of all sorts of fossils, marking various remote stages of past life, evidence of the vast extent of known time, but also the slow rise and fall of plant and animal groups as a whole emphasizes the same point.

The Rôle of Paleontology

To learn the kinds of animals and plants that have lived in former times; to determine just when they lived and what they did; and to find out which lines failed to maintain survivors down to the present time, and why, are some of the concerns of paleontology.

There is a seductive lure in fossil hunting, like that which stimulates the prospector for gold, only in the case of the paleontologist it is intellectual gold that he is after, the acquisition of which is of much more inestimable value than the discovery of the yellow metal.

For those who care to look into this matter of past life, and for those who would like to share some of the joys of the exploring paleontologist, there follows a short list of books, which is recommended to point the way.

SUGGESTED READINGS

Lucas, F. A., *Animals before Man in North America*, D. Appleton Co., 1902.

An excellent popular presentation of ancient animal life.

Lull, R. S., *Fossils*, The University Society, 1931.

A short stimulating introduction to the life of other days.

Merriam, J. C., *The Living Past*, Charles Scribner's Sons, 1930.

On the subject of earth history, the President of the Carnegie Institution can converse with the young as well as with the old.

Shimer, H. W., *An Introduction to the Study of Fossils*, The Macmillan Co., 1914.

A valuable textbook of paleontology interpreted through the study of existing forms.

Sternberg, C. H., *The Life of a Fossil Hunter*, Henry Holt & Co., 1909.

The adventures of a typical American who hunted fossils when railroads were new in Kansas, Texas, and the Dakotas, and Indians were more in evidence than automobiles.

THE EPIC OF EVOLUTION

PREVIEW. The universality of change · Adaptations · Making the best of it · Kinds of organic adaptations: Structural; embryological; physiological; psychological; genetical; ecological; physical; biological · Evolution · Evolution and miraculous creation · The nature of scientific evidence · Evidence from comparative anatomy; the key to comparative anatomy is organic evolution · From embryology · From classification · From distribution · From fossils · From serology · From human interference · Environmental theory of Lamarck · Natural selection theory of Darwin: Variation; overpopulation; struggle for existence; survival and elimination; inheritance; isolation · Mutation theory of DeVries · Germplasm theory of Weismann · Other theories · Conclusion · Suggested readings.

PREVIEW

Observable inborn as well as acquired CHANGES in animals and plants, and in their surroundings, necessitate ADAPTATIONS and ADJUSTMENTS on the part of organisms which, if inherited, result in EVOLUTION.

To challenge, analyze, and expand the ideas contained in this statement is a large order. It will require full and willing co-operation on the part of the reader, who is expected to think as he reads of cases from his own observations and experience that bear upon the general propositions advanced.

It is freely admitted that, with such an ambitious thesis as this, one is tempted to take now and then to the aerial route of speculation, and to generalize with panoramic views of the whole, when to particularize with illustrative details might be more illuminating and to the point. The contributing reader is consequently hereby warned in advance to keep one eye at least on the solid ground of fact below, whenever, by flights of fancy and theory, he finds himself being hurried to his destination by the more rapid and less substantial air route of speculation.

The Universality of Change

It is a matter of common experience that everything which we can observe about us eventually undergoes change.

Although it may be necessary to extend the duration of observation in order to detect the occurrence of something different as happening, nevertheless, it always comes about in the end. The apparently stationary hour-hand of a clock, for example, is known to shift its position during the day, in spite of its appearance of standing still.

That no structure or action remains constant and enduring is particularly evident in living things, in which change is inevitable from the cradle to the grave, not only in mankind but also in the daily life of every animal and plant.

Furthermore, if it were possible to take a complete census of all the different kinds of organisms represented on the earth today, for comparison with similar censuses taken during the different geological periods, sweeping changes in the character of whole groups would at once be apparent. Even with the partial census which biologists have been able to make of organisms known to have existed in the past, as contrasted with the catalogue of living forms thus far discovered, it is proven without a doubt that the Law of Change is now, and always has been, everywhere in constant operation.

The causes, or sequences of events, leading up to all sorts of changes are naturally diverse and numerous. With organisms they may be inborn, that is, genetic in character, or largely external and environmental, but in any case, the *fact* of change with its consequences is observable and can be analyzed, even though the underlying causes that bring these changes about are often uncertain and unknown.

Sometimes changes, in themselves slight, may have far-reaching consequences. For example, when single-celled organisms, accustomed from time immemorial to divide periodically each one into two individuals, discovered the great advantages of partnership and remained attached to each other after fission occurred, instead of separating and going their independent ways, right then was born the pregnant idea of tissues and organs. The device of cell multiplication opened up consequent possibilities of the working together of parts for greater effectiveness, through the fertile principle of "division of labor." This change was a great historical event in the world of life, with extensive sequels.

Again, when by gradual changes the shift from a single parent to the sexual method of two parents came about, another great biological epoch began in which, by utilizing two hereditary streams

instead of one, the possibilities of the offspring of successive generations were more than doubled.

Take one more illustration of a series of changes that has altered the whole course of subsequent biological events. The bilateral symmetry of locomotor animals, that is, those having a head end and right and left sides to the body, was preceded by the radial symmetry of attached forms like Hydra, an arrangement making it possible from a point of anchorage to explore the surroundings for food in every direction without the machinery of locomotion. When animals with radial symmetry become free-swimming, like jellyfish and sea-urchins, they go at random in any direction. It is only after one definite part in the circumference of a radially symmetrical animal constantly takes to leading the way that a head end is initiated, with a brain center to direct the increasing activities of the changing animal. The connecting links in this chain of changes between radial and bilateral animals are to be seen in certain turbellarian flatworms, whose fundamental plan is the same as that which would be formed if a radial jellyfish were stretched out lengthwise with one horizontal axis elongated, thus forming a polar arrangement with head and tail ends. It may be a long call to return thanks to these lowly creatures for discovering the advantages of a head with a directive brain in it, but perhaps it is not too late at least to register our gratitude.

There is much variation in the degree of plasticity shown by organisms and in the range of changes which they undergo. Some forms, like certain brachiopods and shell-bearing protozoans of the deep sea, are so well fitted to the constant habitat in which they live, where there is no variation of pressure or temperature, and where no day or night intrudes upon their tranquillity, that those living now have not changed perceptibly in appearance from their extremely ancient forebears.

On the other hand, in the strenuous environment of the tidal zone, where land and restless waters meet, the inhabitants are kept constantly busy and alert in matching structural and functional changes with insistent and recurring changes in their surroundings. Thus it is that changes in the environment necessitate continuous adjustments on the part of plants and animals. Whatever may happen meantime to the individual actor, the *show must go on*. This tradition of the dramatic stage is quite as true also for the larger stage of changing life.

ADAPTATIONS

Making the Best of It

Adaptations are biological changes that organisms make in adjusting themselves to physical changes which constantly occur in the environment. Here are two variables to analyze and consider, namely, changes made by the organism, and those that come to pass in the environment of the organism. How do they interact?

Organic adaptations vary widely in the degree of perfection. They may be incipient, partial, and ineffective, or, at the other extreme, they may have gone so far as to result in overspecialization. This latter condition is frequently dangerous to its possessor, since the specialist, having all his eggs in one basket, cannot help sacrificing some of the saving adaptability necessary to meet a changing turn of the environmental wheel. This is particularly true in human affairs. The hobo who is limited to snow-shoveling is unemployable in the summer season.

Many instances of adaptation are entirely obvious. Others are obscure and speculative, but in any case the extensive gallery of common adaptations furnishes abundant and intriguing material for the biologist. "Maeterlinck's essay on the adaptations of the bee," says Henshaw Ward, "makes the *Arabian Nights* seem flat."

Kinds of Organic Adaptations

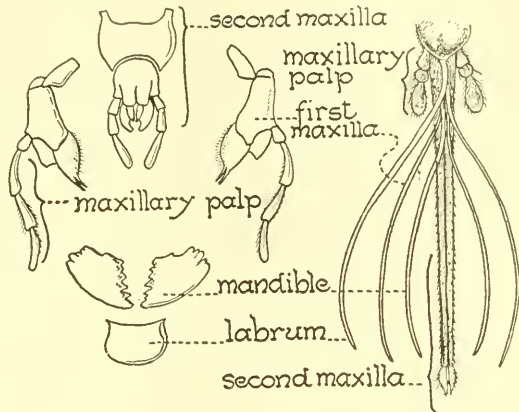
The classification which follows is entirely arbitrary and by no means complete. It is simply an attempt to arrange certain categories of adaptation temporarily for purposes of description. There is such a wealth of illustrative material that it is almost hopeless to attempt to pick and choose. Consequently, resort will be made more to suggestion than to detailed elaboration of particular cases. Here is an excellent opportunity for the reader to fill in omissions with supplementary material of his own.

Structural Adaptations

The elaborate mouth-parts of insects are all designed apparently on the same fundamental plan, but this plan is carried out quite differently in the "tobacco-chewing grasshopper," which feeds on vegetation, and in the prodding mosquito, that sucks blood out of protesting humans.

The size of an animal may be in itself a structural contribution to success in life. A single horse that weighs a ton and a ton of mice both require in general the same sort and amount of food, but the mice stand the better chance of getting about and securing food necessary for maintaining a ton of protoplasm.

Some other random suggestions of examples of structural adaptations are radial symmetry in sessile animals, the histological structure of leg bones adapted to bear body weight, the handy, prehensile tails of South American monkeys, the



The cockroach (left) and the female mosquito (right) inherit a homologous set of mouth parts, which have become considerably modified to meet the conditions imposed by different functions.

sharp claws of certain bloodthirsty carnivores, the sticky protrusible tongue of ant-eaters, the snowshoelike feet of the Mexican jacanas, which get their insect food while skipping lightly over floating lily-pads, the elongated snouts of chestnut weevils that have the problem of spiny burrs to solve, and the shoelike hoofs of heavy ungulates.

Embryological Adaptations

Reptiles and birds, that hatch by breaking through an enclosing eggshell after making a preliminary start in life, and mammals, which go through the early stages of their development in safety within the mother's body, have to be fitted successively for two quite different sets of conditions. Such embryos, during the period of their imprisonment, employ two notable adaptive devices, the *amnion* and the *allantois*, which are discarded upon emergence. The amnion is an enveloping antenatal robe, filled with fluid, within which the delicate, rapidly growing embryo floats, protected from mechanical shock and from growth-checking exposure to a dry world. It is an adaptation to land life quite unnecessary in the case of fishes and amphibians, whose usually shell-less eggs are deposited in the water during the period of their preliminary development. The allantois is a make-

shift respiratory device, effective within the eggshell, or, in the case of mammals, in the uterus of the mother, before it is possible for the lungs of the young individual to take over the task of respiration.

Curiously, the embryologist often has to describe a different organ from that which the anatomist cites for the accomplishment of the same function in the animal body. An adult anatomical structure over and over again succeeds a transitory embryonic forerunner. Thus, temporary *nephroi* are followed by permanent kidneys; downy *lanugo* is replaced by hair, more or less permanent; the gauzy embryonic covering of *epitrichium* gives way to the adult skin; there is a succession of teeth; the intestine replaces the *yolk sac*; the primitive *vitelline circulation* gives over its temporary emergency service as the systemic circulation arises; the two-chambered, fishlike, embryonic heart of the mammal becomes replaced by the three-chambered amphibian stage before the final four-chambered heart is established; while for the embryonic vertebrate skeleton, patterned largely in cartilage, there is eventually substituted a more efficient bony framework.

All these illustrations and many more indicate adaptations to adult life, following the different preliminary conditions imposed by embryonic existence.

Physiological Adaptations

When for any reason one kidney is removed, or put out of commission, the remaining kidney assumes the double task and increases correspondingly in size. This is a physiological adaptation.

The apparatus of the sweat glands is a physiological device enabling mammals to adjust themselves to the greater variation in temperature which occurs on land, as contrasted with that to which sweatless water animals are exposed.

A grasshopper, with its large immovable compound eyes facing everywhere except below where the mouth is located, is not able to see the food that it is eating, so tactile palps, that are sensory modifications of the mouth-parts, become adapted to function instead of eyes in the examination of food.

Darwin cites the strange case of a certain species of parrot in New Zealand which, after the introduction of large herds of sheep into its habitat and after somehow getting the taste of blood, gave up its former vegetarian habit of life and became a murderous, blood-thirsty carnivore, living entirely on the flesh of sheep.

The activation upon occasion of the mammary glands, as well as the formation of antitoxins, and the acquisition of immunity to certain diseases, are further examples of physiological adaptation to bodily needs.

Psychological Adaptations

Patterns of instinctive behavior which adapt an untaught caterpillar to spin a cocoon of a definite sort, or direct an insect to lay its eggs upon a particular food-plant specific for its offspring which it will never see, as well as the inner urge that causes birds, and certain other animals, to migrate periodically, may possibly be cited as examples of psychological adaptation. At any rate, the exercise of the nervous system that enables actors to repeat their lines unconsciously in dozens of plays, and by which musicians are able upon repetition to perform complicated and extensive scores without conscious effort, comes close to being an adaptation of a psychological nature.

Genetical Adaptations

Adaptations frequently work for the benefit of the species rather than for the welfare of the individual.

The clever dandelion grows close to the ground in a flat rosette. This habit enables it to escape from browsing animals to a considerable degree and to withstand trampling. Its yellow blossom lies low and bides its time until all is ready and then, just at the critical time, the hollow stem shoots up like a fire ladder into the air almost overnight, bearing a cluster of white-tufted aviating seeds that are all prepared for distribution. They are so delicately poised, pincushion-fashion, in their elevated position that the slightest breeze is sufficient to waft them on their way.



The adaptable dandelion, providing for itself and for its progeny.

All the many reproductive modifications, both structural and functional, which are involved in the fertilization of animal eggs as well

as in the formation of spores and seeds of plants, make up a world of adaptations in themselves that, since they have to do with the maintenance of species, may be considered as genetic in character.

Another genetic adaptation, that is so universal as to be properly regarded as a law of nature, is shown in those animals and plants whose reproductive products are particularly exposed to great perils, and which in consequence produce a correspondingly larger number of eggs or seeds than do those whose offspring are better safeguarded. Nest-building in all its diverse forms, as well as the multitudinous devices employed by plants to secure pollination and the dispersal of seeds are further examples of genetic adaptation.

Ecological Adaptations

Any group of varying organisms, adjusted more or less imperfectly to a certain habitat, tends in the course of time to branch out and to occupy different neighboring habitats. Adaptation to new habitats is ecological adaptation. This type of adaptation has been somewhat amplified in unit II, on the "Biological Conquest of the World," and innumerable examples of conditions met in the great primary habitats of water, land, and air will come to the mind of every observing reader. If animals could talk and had intelligence enough to know what to say, think what tales they could rehearse of the troubles they have known and the satisfactions they have experienced in becoming adapted to their particular niches in nature! Imagine, for instance, a *Thousand and One Nights* spent in listening to such representative spokesmen as the hermit crab, the nocturnal earthworm, the carrion beetle, the golden plover, the sperm whale, the liver fluke, the snake in the grass, and the bullfrog on the bank. Even the plant world could be profitably admitted to take part in such a symposium. For example, what might the northern pine and the southern palm, the roadside weed and the head of rice, to say nothing of the bacteria of "Typhoid Mary," have to tell us of ecological adaptation!

Physical Adaptations

Certain factors in the make-up of the physical environment, such as temperature, pressure, and light, set limits within which organisms must adapt themselves in order to live. The range of livable possibilities imposed by these physical factors varies greatly with the organism. Professor Brues of Harvard reports that there are algae

and the larvae of certain insects that are adapted to live in hot springs, the temperature of which is sufficient to coagulate the protoplasm of most organisms. Some animals, frogs for example, can survive a degree of freezing that would be fatal to others. Trees and woody shrubs can successfully withstand low temperatures that cause most of the less woody plants to succumb. The varying range of frost and heat to which plants of different sorts are susceptible is common knowledge to every farmer.

Adaptive devices, such as *gemmules* of fresh-water sponges, the *winter eggs* of daphnids, and the *statoblasts* of certain bryozoans,

carry these lowly animals through the freezing winter into another summer quite as effectively as the various coats and shells of seeds and nuts. Again, warm-bloodedness is an adaptation fitting birds and mammals to cope successfully with great and often sudden shifts in temperature on land, to which the cold-blooded inhabitants of water are not subjected.

Pressure is another physical factor to which every organism, in order to live, must be adjusted. Most animals and plants living on the surface of the earth, beneath a uniform blanket of atmosphere, are not subjected to much difference in pressure, but deep-sea fishes, with an additional weight of superimposed water, have quite a different problem to meet. This particular form of adaptation



American Museum of Natural History

A deep-sea group of fish: left, *Macrurid*, and right, *Brotulid*.



American Museum of Natural History

Oceanic angler fish, *Linophryne*. The beard is probably luminous.

consists not so much in protective envelopes of one kind and another, that must inevitably be crushed, as in the development of easily permeable tissues through which the pressure is equalized.

Light is essential to photosynthetic plants. These exhibit many adaptations by way of the arrangement and form of their leaves to secure adequate exposure to light. There are many kinds of animals on the other hand, like cave-dwellers and deep-sea forms, as well as fungi among plants, that can dispense with light entirely. In such animals, the eyes and other adaptations to a world of light and shadow are either entirely wanting or have become degenerate. To compensate animals that live in darkness for their loss of light, tactile devices of various sorts develop, enabling them to find their food and to accomplish the business of living, while in the case of plants the saprophytic method of living a chlorophyll-less life is adopted.

The reflex mechanism in the iris of the eye by which the size of the pupil is made to vary and the amount of light admitted to the retina is regulated is a beautiful adaptation of the organism to amount of light. In fact, the whole vertebrate eye is an exquisite example of cumulative organic adaptation to the environmental factor of light.

Biological Adaptations

The association of organisms with each other gives rise to a great variety of biological adaptations, such as symbiosis, commensalism, saprophytism, parasitism, gregariousness, and social life.

Flowering plants evolve ways of attracting the visits of insects and of inveigling them to transfer pollen in the production of seeds. Insects in turn are so modified as to take advantage of what the flowering plants offer them by way of nectar and other desirable forms of food. It is significant that flowering plants did not develop in geological time until after insects appeared.

Carnivorous hunters are fitted to pursue their prey, and the hunted, by developing speed in flight or by wits with which to outguess the pursuer, are adapted to escape. Mother Nature impartially gives both the hunter and the hunted a sporting chance.

Through protective coloration and camouflage, by bluffing with warning colors, or by intimidating behavior, some animals escape their enemies, while others are blackmailed into surrendering to their captors a part of themselves and escaping with a viable residue, having in reserve the adaptive resource of regeneration of lost parts.

There is a curious European toad, *Bombinator igneus* by name,

that has developed a bright scarlet belly and a taste nauseous to birds, in the course of its adventures in adaptation to an environment unfortunately shared with toad-devouring storks. When a stork by chance seizes a bombinator, the victim is usually ejected because of the acrid taste produced by the skin-glands of the toad. Neither stork nor toad gains anything by this performance, and, to lessen the likelihood of its occurrence, whenever a stork swoops down upon a pond where bombinators are socially congregated around the margin, the little animals quickly flop over and expose their conspicuous scarlet bellies to view, thus furnishing red-light signals for the stork to "stop," before an accident happens that both would regret.

A great variety of defensive devices, such as armor, shells, spines, fangs, horns, hoofs, and stingers, have been developed in different animals. The nonchalant skunk is so well assured by its defensive fire extinguisher mechanism that it does not run away from danger. This may be why so many of them, upon the intrusion of the juggernautlike automobiles into their habitat, are run over and killed, while the more cautious rabbits and other wayside animals escape.

Plants display a great range of biological adaptations in the attempt to defend themselves against browsing herbivores and devouring insects. Some plants have bitter or unpalatable chemical substances lodged in their tissues. Cacti and thistles bristle with discouraging spines, while shrubs and trees are provided with tough resistant bark. Desert plants develop fuzzy hairs that hinder transpiration, or are coated over with an impervious varnish that tends to prevent the loss of water from their tissues.

There may be still other categories of adaptations, and some of the foregoing examples could perhaps be assigned to other classifications, but the undeniable fact remains that adaptations of infinite variety characterize the living world about us.

EVOLUTION

Evolution and Miraculous Creation

Perhaps two of the most famous scholars of the ancient English universities of Oxford and Cambridge were John Milton (1608-1674) and Charles Darwin (1809-1882). Each wrote an immortal book upon the same epic theme of how living things in this world came to be as they are. Milton's book was entitled *Paradise Lost*, and

Darwin's, *The Origin of Species*. Milton's answer, couched in stately poetry, was that the forms of life were suddenly created by divine fiat out of the "dust of the ground," without any organic predecessors, while Darwin's plain prose presented overwhelming evidence of the gradual evolution of present animals and plants from earlier forms of life.

This latter conception did not originate with Darwin. The ancient Greeks, unhampered by any Biblical tradition of "creation," foreshadowed the idea of the rise of organisms by the slow operation of natural laws. Centuries later, Saint Augustine of Numidia (354-430), with panoramic vision, expounded the same view, and still others from time to time got glimpses of the majestic canvas depicting the progressive pageant of life. Among the more recent of Darwin's forerunners was his own grandfather, Erasmus Darwin (1731-1802), who wrote a compendious work of rather poor poetry entitled "The Botanic Garden," in which the theme of organic evolution was developed. Major Leonard Darwin (1850-), distinguished son of Charles Darwin and leader in England today in developing the related field of *eugenics*, has carried on the Darwin family tradition of making evolution plain to the world. He defined evolution in his book entitled *The Need for Eugenic Reform* as "the gradual building up, in accordance with the laws of nature, of the world as we now find it, from some unknown beginning."

It is common observation that one individual arises from another. Organic evolution is simply an extension of this principle to include those groups of organisms called species. The evolutionary principle is everywhere observable, even in other than strictly biological fields. The earth, the solar system, and the far distant heavenly galaxies have all been evolved. Human society, language, and customs have come about by the operation of the same type of universal sequences. Even our idea of God has evolved from that of the originally exclusive individual household god, up through tribal gods, and the more inclusive national gods, until finally there has been accepted the idea of universal human brotherhood with one God over all.

The idea of miraculous creation, which was quite acceptable to the mystical Eastern mind centuries ago, has lost its potency with the logical Western mind of today. There are everywhere observable too many partial and imperfect adaptations and misfits to represent the handiwork of an intelligent and skillful creator, if miraculous creation, with the possibility of immediate perfection,

was the method employed. It is illogical and impious to postulate the Creator as a bungling and slipshod workman.

In spite of controversial echoes from the past, there is nothing alarming or unsettling in the concept of biological evolution. There is no more conflict between it and religious faith than there is in Galileo's demonstration, which so worried his contemporaries, that the earth moves around the sun. The religious person and the evolutionist both approach the citadel of truth with equal reverence, but from somewhat different directions. There is nothing to prevent their harmonious meeting within the portals.

While the *facts* of evolution are comparatively plain, the *factors* that determine how it came about are still uncertain and debatable. Darwin, in *The Origin of Species*, not only marshaled in thoroughgoing and masterly fashion the facts in support of evolution, but he also went further and advanced his "Theory of Natural Selection," to be considered in a later section, in the attempt to explain *how* evolution has occurred. A consideration of the facts of evolution calls for evidences which are derived from many sources. Just as "all roads lead to Rome," so various lines of evidence about to be presented converge to establish the general truth of organic evolution.

The Nature of Scientific Evidence

What is evidence to one person may not be to another. The yokel at the circus who exclaimed, "There ain't no such beast," when he saw a giraffe for the first time, could not easily accept the evidence of his own eyes. It would be futile to try to convince a cat that a picture of a mouse, however well done, really represents a live mouse. The cat lacks experience in judging pictures and is unable to gain such experience, so that the idea that a picture has anything whatever to do with a real mouse is beyond the cat's comprehension.

Sufficient intelligence, a background of experience, and an open mind are essentials in understanding what any evidence means. The more technical the matter presented, the greater the intelligence and experience required to evaluate it. Moreover, since it is quite out of the question to acquire at first hand all the knowledge and experience of which we make use, it is necessary many times to accept the judgment of others who are experts in fields more or less unfamiliar to us. Distinguishing marks of a truly educated man are not the only possession of a considerable store of first hand

information, but also the ability and willingness to appreciate what others have accomplished, and to judge with discrimination what persons are properly qualified to serve as authorities on any particular subject.

The attitude of the uninformed and unintelligent, when confronted with evidence that lies somewhat beyond their horizon, is frequently bewilderment, retreat to the strongholds of prejudice and hearsay, or indulgence in the smoke-cloud of contempt or derision for that which they do not comprehend. It is among those that lack discrimination in the acceptance of evidence, and who fail to pick properly qualified authorities on whom to depend for whatever lies beyond their ken, that all sorts of undesirable propaganda and muddy thinking find soil in which to flourish. Moreover, it is usually a waste of time to present evidence to a prejudiced and closed mind, to one that confuses argument with evidence, or who is guided by emotional likes and dislikes rather than by a deep-seated confidence in truth, wherever it may lead. Many lines of evidence in any case have to be taken on faith, since they cannot fall under the direct inspection of the senses.

"Never in its life has the sun seen the shade,
 Never in its life seen a shadow where it falls;
 There, always there, in the sun-swept glade,
 It lurks below the leaf; behind bodies, under walls,
 Creeps, clings, hides. Be it millions, be it one —
 The sun sees no shadow, and no shadow sees the sun."¹

What the poet says of sun and shadow clearly expresses the idea that evidence may be both true and acceptable, although as elusive to the senses as shadows are to certain sunlike minds. In a consideration of the evidences of evolution, it is appropriate to call in the testimony of various biological sciences, which presuppose more or less familiarity with them, and training therein, to fully appreciate the force of the facts presented.

Evidence from Comparative Anatomy

Comparative anatomy is a biological science rich in significant problems and their solution. It arose from the dead descriptive level of the older science of *human anatomy*, which in turn, unless interpreted in the light of comparison with that of other animals,

¹Laurence Houseman, from Shipley, in *Life*, page 31. By permission of The Macmillan Company, publishers.

remains largely meaningless and puzzling. The problems that human anatomy presents are illuminated and largely solved by recourse to comparative anatomy.

The Key to Comparative Anatomy Is Organic Evolution

A mere description of the structure of different kinds of animals and plants would in itself be monotonous and colorless, an uninterpreted mass of isolated facts, were it not that a thread of relationship, connecting these forms of life with each other, gives significance to the whole. *Identity of plan, based upon derivation from a common stock, with adaptive variation in the working out of that plan to meet changing environments or new functions*, is the creed of the comparative anatomist, by which he makes sense out of what he observes.

Goethe (1749-1832), in whom superlative excellence as a poet overshadowed his real greatness as a pioneer biologist, pointed out that the sepals, petals, stamens, and pistils of flowers are to be interpreted as modified leaves, crowded together on a short stem, to meet the requirements of a different function. Again, an examination of the hearts of different vertebrates, for example, shows an evolving series of structures as illustrated on page 306. The fish heart is a single pump, with a thin-walled atrium receiving the returning blood, and a muscular ventricle for pumping it over the body. In the amphibian the single pump begins to become double by the introduction of two atria, thus making a sort of heart-and-a-half arrangement, while in most reptiles, by the formation of a partial ventricular septum, the organ is advanced to become a heart-and-three-quarters. Finally, in the crocodiles, birds, and mammals, the heart becomes a double pump with two auricles and two ventricles. This continuous series of modifications the comparative anatomist interprets as due to progressive evolution based upon relationship.

Inspired by Darwin's "Origin of Species," the eminent German anatomist, Robert Wiedersheim, has written a remarkable book¹ in which he describes in charming and scholarly manner a long array of human anatomical structures that in every instance are matched by corresponding details exhibited by other vertebrates. He concludes that there is nothing unique or original in the "structure of man." Even such differences as appear in the distinctive human brain as compared with the brain of his "poor relations" in the animal kingdom, are quantitative rather than qualitative.

¹ *Der Bau des Menschen*.

An outstanding example of common origin that is frequently cited is the case of homologous bones in the wing of a bird, the leg of a quadruped, the flipper of a whale, and the arm of man, which conform to a common plan but develop into diverse structures for different uses.

One of the blood ties that suggests the cousinship of all vertebrates is the fact that they are limited to two pairs of lateral appendages, although some of them have lost one or both of these pairs. A learned doctor's thesis in biology that could satisfactorily explain the presence of wings in addition to arms on the shoulders of the angels which Raphael painted on the ceiling of the Sistine Chapel in Rome would be as famous as the frescoes themselves. The only possible conclusion acceptable to the comparative anatomist would be that angels and men are entirely unrelated, which may be true enough.

When representatives of animal groups are passed in review in the mind's eye, all sorts of different structures, such as skeleton, kidneys, teeth, sense organs, brains, and respiratory devices, fall into line as being made up of a continuous series, explainable upon the supposition that they have evolved one from another during the long course of geologic time, but that otherwise are unintelligible. It is quite impossible for a comparative anatomist, grounded in the knowledge of many details, not to be convinced that the leg of a horse is one end of a series of structural modifications that began with the fin of a fish. Or that the plan represented in the life cycle of the flowering plants is not the outcome of the alternation of gametophytes and sporophytes so apparent in the mosses and ferns. All the necessary connecting links are there, which would be senseless indeed if they did not fall into line to spell continuity. Innumerable examples of this sort are familiar to the biologist.

As has been pointed out by certain doubting Thomases, the fact that things may be arranged in a continuous series does not necessarily mean genetic relationship. Weapons of human defense, for example, may be traced from their earliest beginnings in the form of stones and clubs, up through spears, bows and arrows, and firearms of increasing efficiency, to the deadly machine gun, yet no one would say that this is *genetic* derivation of one kind from another, because weapons of defense do not reproduce their kind as do living things. The U. S. Patent Office is well aware that the same idea often turns up from widely different sources having no possible immediate connection.

Likewise there is frequently a convergence of structure on the part of diverse organisms, as a result of adaptation to a single kind of environment. When this happens in the organic world, it is called *convergent evolution*, and it puts the comparative anatomist on his guard, since resemblance between organisms does not always signify relationship. Pelagic animals of the open ocean, belonging to the quite different groups of coelenterates, molluses, crustaceans, worms, tunicates, and fishes, often become more or less transparent, which makes it difficult for them to be seen by ravenous fishes from below, or by preying birds diving down from above. Snakes, blind caecilians, legless lizards, and eels, all have attained a similar body form, but innumerable other anatomical features that they severally possess prove them to be not closely related, in spite of their external resemblance. Most cases of convergent evolution are functional rather than structural. Organisms show their relationship to each other by their structure, that is, by *what they are*, rather than by their function, that is, by *what they do*.

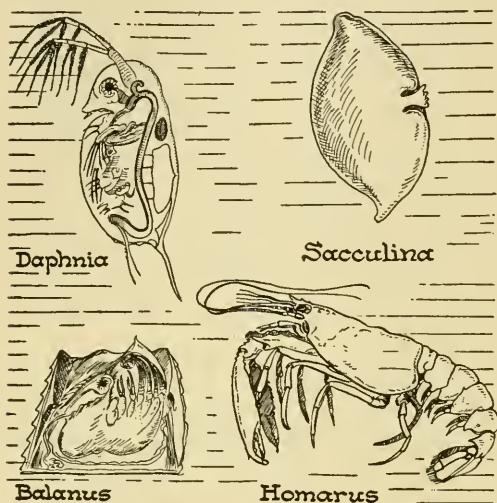
Vestigial structures, such as the well-known degenerating vermiform appendix in man, that is absent in the cat but excessively developed in the rabbit, are anatomical parts gradually disappearing below the horizon of usefulness. Like certain finicky parlor boarders, they often make trouble and there is no accounting for their presence except upon the theory of evolution. Again, as a final example, may be cited the *lumbar plexus*, which is a union of spinal nerves to supply the hind legs of vertebrates. The fact that some snakes have a lumbar plexus, although they have no legs to be supplied with nerves, indicates that they are still hanging on to the documentary evidence that establishes their relationship to other vertebrates, although they have diverged far from the ancestral stock.

Evidence from Embryology

There is a suggestive parallel between the embryonic development of the individual and the more extensive course of organic evolution. A whale and a mouse, both mammals, are more alike in their development than a whale and a fish, which are outwardly more similar. Again, that curious living fossil, the horseshoe crab *Limulus*, which has retained its conservative individuality as a species since paleozoic times, looks anatomically like a crustacean. Its embryological development, however, as Kingsley has demonstrated,

makes more probable its relationship to spiders and scorpions, a conclusion which is confirmed physiologically by blood tests, as will be pointed out later.

The microscopic water flea *Daphnia*, the sedentary rock barnacle *Balanus*, that according to Huxley "stands on its head and kicks



food into its mouth with its legs," the amorphous parasitic degenerate lump *Sacculina*, sometimes infesting the abdomen of crabs, and the familiar free-swimming lobster *Homarus*, are very diverse in adult appearance. No one would ordinarily suspect them of being related, yet an examination of their embryonic history reveals unmistakably that they are crustacean cousins all of one blood. Thus does *embryology*, the science concerned with the development of the indi-

These four extremely unlike animals, fitted for quite different careers, all have in common the heritage of the crustacean plan.

vidual, furnish evidence of relationship that otherwise may not at once be apparent.

The everyday miracle of adult organisms developing from eggs or seeds loses much of its force because of its very familiarity. We cease to wonder that a chick can hatch out of a hen's egg, or that a gorgeous flower can arise from a seed buried in the ground, because its repeated occurrence comes within the span of our everyday experience. If we could live and observe for a million years, no doubt the panorama of evolution would become as obvious, and be as unquestionably acceptable, as that of individual development.

The fact that our horizon is limited by a span of "three score years and ten" foreshortens our vision so that we lose the perspective needed to make the picture clear and in focus. The limitations of human life are in this respect a decided handicap to a more complete understanding of evolutionary processes.

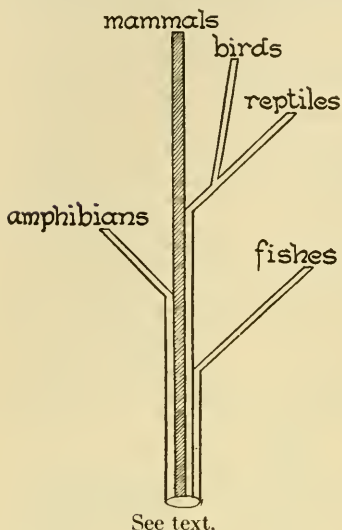
The presence of useless vestigial structures, left behind during the forward march of individual development, furnishes a hint of former differences in the ancestral make-up, and is evidence that evolution has occurred. For example, the useless downy hair (*lanugo*) that covers the entire body, including even the face, of the human embryo during its earlier stages is at least a reminder of other mammals that are clothed all over with hair. It is hard to explain such cases except upon the supposition of relationship and the evolution of one form from another.

A garage with horse stalls and mangers in it would obviously be a horse barn made over to meet the modern demands of the automobile. The stalls and mangers, like the vestigial organs that it has not been imperative to remove, indicate not a "specially created" garage, but the evolution of a horse barn into a garage. Embryology is rich in instances of vestigial organs which point to the fact that evolution has been going on.

But the idea that *ontogeny*, or the development of the individual, faithfully repeats *phylogeny*, that is, the ancestral evolution of the race, though certainly very suggestive, nevertheless has its limitations. In the first place it is too much to ask of a hen's egg, which can develop into a chick in three weeks, to rehearse word for word a phylogenetic story that has required a million years to accomplish. Countless episodes would naturally have to be omitted. Certain embryonic structures, moreover, such as the yolk sac, the amnion, and the allantois, have no counterpart in the adult ancestry of the race. Another limitation is that the larval stages, exposed to environmental adjustments, may become modified into temporary emergency devices having no phylogenetic significance.

There have been various attempts to make sense out of the obvious parallel between embryonic development and organic evolution. The *Recapitulation Theory*, or as Haeckel (1834-1919) named it, the "Biogenetic Law," assumes that higher forms of life during their embryonic development pass through stages attained by adult organisms of the lower orders. Fishes, amphibians, reptiles, birds, and mammals, for instance, beginning alike at the egg stage, become adult by stopping at various levels, as shown in the figure at the bottom of page 502, in which the vertical lines represent embryonic development, and the horizontal lines the attainment of the adult condition. The vertical line of mammals at the right represents ontogeny repeating phylogeny.

Earlier Agassiz (1807-1873) pointed out that the embryo of higher forms does not so much resemble the adults of lower *living* forms as it does adults of lower *fossil* forms.



Von Baer (1792-1876), "Father of Embryology," maintained that the more nearly the adults of two groups resemble each other, the longer their embryonic development follows an identical path. To the evolutionist resemblance of this kind means relationship. This concept is diagrammatically shown in the figure at the left in which it is evident that mammals, for instance, are more nearly related to reptiles than to fishes, because they tread the embryological road together for a longer period.

Morgan (1866-) proposed a "Repetition Theory," in which the embryonic stages run along *parallel* lines, rather than in one composite line, to diverge eventually into adult stages. This idea precludes the possibility that the embryonic stages in any one group could be represented by adult ancestral stages of another group. The adult mammal, for instance, does not look back upon the adult

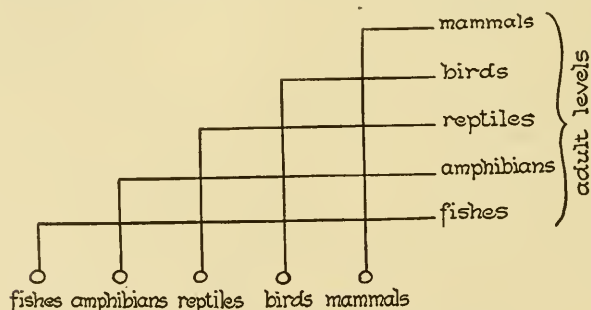
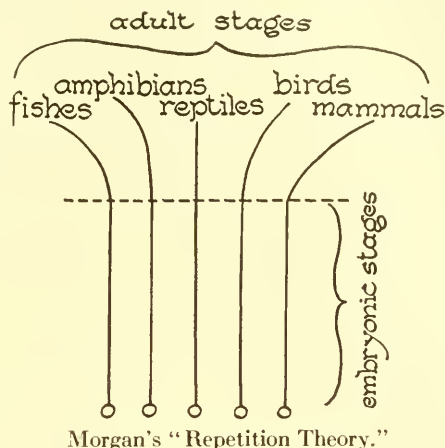


Diagram illustrating ontogeny and phylogeny.

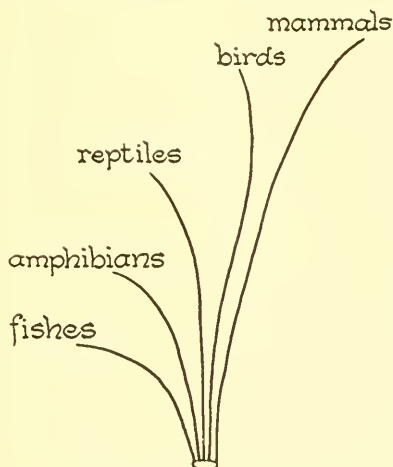
fish as one of the embryonic stages through which it has passed, but apparent resemblances are to be accounted for on the ground that the development of the mammal runs parallel with that of the fish, and consequently resemblances are to be expected.

Hurst (1870-), on the other hand, thought of the lines representing the embryonic stages as divergent rather than parallel, since the farther back one traces the ontogeny, the greater the resemblance between different lines. Morgan in reply suggested that the reason for this observation, indisputably true, may be because there are fewer available diagnostic features upon which to base differences the farther one goes back in development.

Finally, O. Hertwig (1849-1922) has emphasized the fact that the different lines do not all start alike with the same



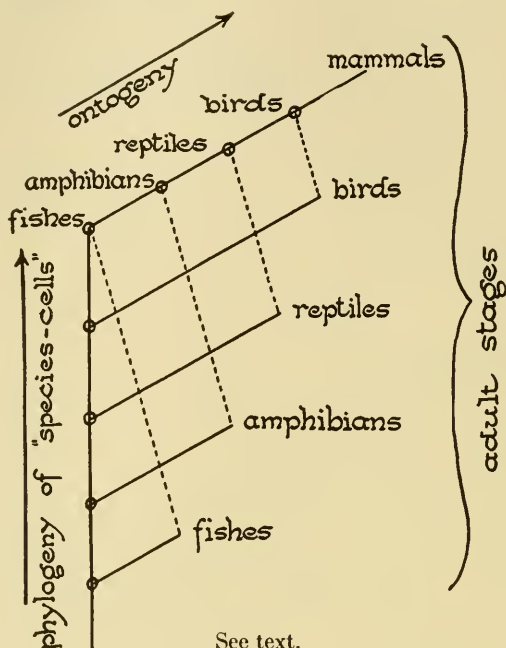
egg stage. There are eggs and eggs. The mammalian egg has possibilities not attained by the fish egg. Thus, the eggs of the various groups, or "species-cells" as Hertwig calls them, have accomplished an evolution in themselves and attained different levels



Divergence theory of Hurst.

The dotted lines in the figure show what would be necessary to assume in order to picture how ontogeny repeats phylogeny.

However, all the foregoing unproven speculations do not invalidate the outstanding fact that similarity of development *suggests* relationship, particularly among forms that have come to be unlike



each other, and implies that evolution has occurred. Why, for example, should a mammal in its development “go around Robin Hood’s barn” in order to pass through a fishlike stage with useless gill pouches, unless such structures were once present, and not yet discarded, in ancestral fishes?

Evidence from Classification

The most natural question anyone asks upon seeing a new or unknown animal or plant is, “What is it?” In the science of classification, or *taxonomy*, the first essential is to identify and to name different organisms. This is no mean task, as there are many thousands of different kinds of plants and animals. According to the Biblical account, the first piece of work that any human being is on record as having accomplished was in the field of taxonomy. “And Adam gave names to all the cattle, and to the fowls of the air, and to every beast of the field” (Genesis 2: 20).

Following the identification and naming of living things, in order to have any intellectual peace of mind it is necessary to arrange them in some sort of order. "Mother Nature" does not do that for us, since her household is everywhere always in bustling delightful confusion. We are forced, therefore, to regulate natural things for ourselves, if we would approach the study of all these forms in any satisfactory scientific way.

When elaborating a reasonable scheme of classification, the taxonomist runs invariably into evidences of evolution. If no other line of evidence had ever been established to prove the truth of evolution, that from classification alone would be conclusive. The criteria which have been found to be most useful in grouping organisms together intelligibly are not superficial or functional characteristics, but the more deep-seated anatomical structures that indicate genetic relationship. It would be quite futile to depend upon a superficial characteristic like the presence of spines, for example, as a standard of classification, since it would bring together such strange bedfellows as porcupines, thistles, *Murex* shells, sea-urchins, and cacti, ending in as much confusion as ever. On the other hand, if some more deep-seated anatomical character is selected, like the backbone, then there can be gathered into one proper fraternal group forms of such diverse appearance as bird, beast, and fish. Or in flowering plants if, for example, such a superficial character as yellow color is employed for purposes of classification, then representatives of families as diverse as dandelions, roses, sunflowers, and witch-hazels would be incongruously bunched together, and everyone knows that would never do.

There are, instead, many available fundamental differences, such as the number and arrangement of the floral organs, which are satisfactory and dependable criteria for classification, because they indicate relationship. External features, that are naturally exposed directly to molding environmental influences, register *where an organism has been*. Internal characteristics more often signify true relationship, and *what an organism actually is*. Although clothes may distinguish a prince from a pauper, underneath both robes and rags "a man's a man for a' that." As Kipling has it, "the Colonel's lady an' Judy O'Grady are sisters under their skins."

Taxonomy actually resolves itself into anatomical and embryological description, since this sort of detail is necessary as a basis for discrimination.

The unit of the taxonomist is the *species*, just as the unit of the anatomist is the *organ*, and that of the physiologist a functioning *system of organs*. Exactly what constitutes a species is still a matter of controversy. Someone has said that a species is simply a compromise of opinions on the part of experts. A species represents a real entity, nevertheless, for it is something that outlasts the mortal individuals composing it. For our present purpose it may be described as a group of individuals more like each other than they are like any other individuals.

According to a time-honored system, larger groups than species, of increasing inclusiveness, are employed in classification, such as genera, families, orders, classes, and phyla. (See unit IV.) Linnaeus, past master in taxonomy, regarded species as entirely separate groups, to be arranged as if in the pigeon-holes of a desk. This was before the evidences of evolution were as well known as they are today. *Connecting links*, however, have played havoc with the pigeonhole idea in classification. A good example of connecting links, dating back to the Jurassic Period, is *Archaeopteryx*, the earliest known reptile-bird, sporting feathers, teeth, and a lizardlike tail. Biological literature is full of such connecting links, plainly indicating relationship and the occurrence of evolution.

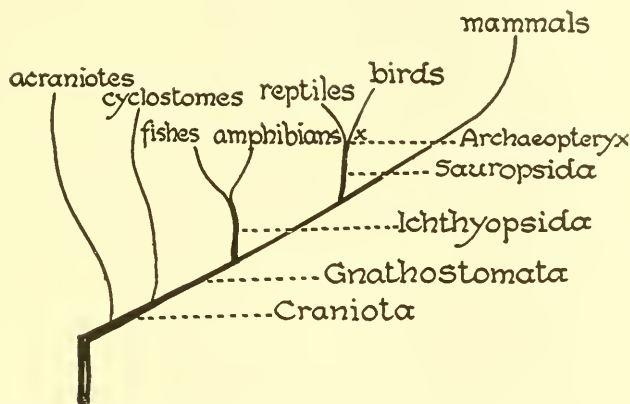


Archaeopteryx, the oldest known bird, drawn from the Berlin specimen. Note teeth, three fingers, feathers, and a lizardlike tail. The only other known specimen is in the British Museum. (After Parker and Haswell.)

The attempt to sort out different species of such groups of organisms as, for example, sedges, mosses, grasshoppers, violets, or fishes, immediately brings difficulty, because the representatives of these groups grade into each other. It takes a specialist to do it. The more nearly two species are related, the fewer and finer are the diagnostic features that can be found and utilized to distinguish them. The dipterologist, for example, is obliged to resort to very minute

technical details in pigeonholing the thirty thousand or so kinds of flies that occur in the United States alone. It is little wonder that many half brothers turn up in such an extensive fraternity.

So it comes about that the taxonomist, while still resorting to convenient pigeonholes in classifying plants and animals, comes more



The theoretical branching of the Craniote tree. X marks the spot where the reptile-bird *Archaeopteryx* roosts.

and more to picture, in his mind at least, a branching tree as the proper symbol by which to represent the obvious relationships that connecting links indicate. A tree with its trunk giving rise to branches and twigs is, in fact, a perfect diagrammatic picture of the evolutionary process. Such a zoological, phylogenetic tree, including only vertebrates, however, is shown in the figure, with X marking the spot where *Archaeopteryx* can comfortably roost.

In a similar taxonomic tree, enlarged to include all animal creation, a watery floating jellyfish on one of the lower branches might humbly look up to an earthworm, with its wonderfully prophetic head end, while arrogant human beings in the very tree-top look down patronizingly upon the scatter-brained monkey, and all other biological way-stations.

Similar taxonomic trees may also be constructed to show what is known about the possible relationship between different groups of plants.

Finally, in summation it may be repeated that the *key to classification is relationship*; that is, the derivation of one form from another, which is evolution.

Evidence from Distribution

The peculiar way in which species of animals and plants are distributed in oceans and upon land finds no sensible explanation unless it is assumed that evolution has occurred, when it plainly becomes a matter of untangling historical events, such as past geological changes and the migrations of plants and animals, and finding out their proper sequence. From their original home the members of each species scatter, due to overcrowding, the search for food, and various other reasons, until they encounter barriers that limit their advance. The species may settle in a new habitat, or undergo transformations and adaptations that make further exploration of the world possible. A species may also perish in the attempt to live in a changing environment to which it cannot adapt itself. Fossil records are filled with examples of this sort. Therefore, the *key to the present distribution of organisms lies in a knowledge of the vicissitudes experienced in the past.*

It was the unusual distribution of life on the Galapagos Islands that started Charles Darwin in his yeasty thinking about evolution, and, as everyone knows, he started others to thinking. These volcanic islands lie 500 miles off the coast of Ecuador, and were visited by Darwin during his famous voyage around the world on the *Beagle*. There he found an assemblage of peculiar animals, all unmistakably patterned after South American forms, but yet modified somewhat from the continental types. It is evident that originally there must have been land connection between South America and what is now this archipelago of volcanic islands, making a bridge over which continental animals could migrate. With the gradual subsidence of the oceanic floor, the tops of the volcanoes were left as isolated islands, and the islanders found themselves cut off from their relatives on the mainland. Survival on these isolated islands called for nice adaptation, different in each different habitat.

South America and Africa have in general the same climate and would be suitable habitats for the same organisms. Nevertheless, the faunas and floras of these regions are quite different. In Africa are found the rhinoceros, lion, wart hog, zebra, baboon, giraffe, gorilla, okapi, and aardvark. None of these animals occur in South America, which in turn is the home of the armadillo, sloth, vampire-bat, llama, peccary, tapir, agouti, and marmoset, not one of which is found in Africa. Such diverse distribution indicates that these

two continents have been separated long enough, even if they were ever in communication, to allow their characteristic faunas to evolve independently.

There is geological evidence of an ancient Pleistocene land-bridge in the region of Bering Strait, between North America and Eurasia. The presence of this former bridge explains why similar native animals, such as bears, sheep, antelopes, moose, bison, and caribou, occur in these two great regions now separated from each other, and are not represented on other continents.

One of the best examples of the connection between evolutionary processes and distribution, which has been unearthed quite completely by paleontologists, is that of the camel-like mammals. The ancestral home of these animals, as shown by fossils, was North America, where they went through a long preliminary evolution, but where none of them are present today. *Protylopus* was an Eocene "camel"; *Poebrotherium* followed in Oligocene times; and *Procamelus* in the Miocene period.

Later, in the Pliocene period some of these ancestral camels migrated in two directions from their birth place. One stream went across the Bering Sea bridge into Eurasia and evolved into Bactrian camels with two humps and the Arabian dromedaries with a single hump. The other stream migrated southward over the Isthmus of Panama into South America, and became modified into the wild guanacos and vicuñas, from which much later the domestic llamas and alpacas were derived. Thus, the transformed descendants of these peculiar ancient fossil forms of North America are found today occupying habi-

EVOLUTION OF THE CAMELS					
Quaternary or Age of Man		Skull	Feet		Teeth
Tertiary or Age of Mammals	Pleistocene				
	Pliocene				
	Miocene				
Tertiary or Age of Mammals	Oligocene				
	Eocene				
Mesozoic or Age of Reptiles		Hypothetical five-toed Ancestor			

American Museum of Natural History
Evolution of the camel.

tats far apart, and are quite different in general appearance, although unmistakably relatives.

In conclusion may be quoted the eminent paleontologist, W. B. Scott (1858-), who says, "The main outline of the problem of distribution has been satisfactorily explained on the evolutionary theory, and no other theory even pretends to account for the facts."

Evidence from Fossils

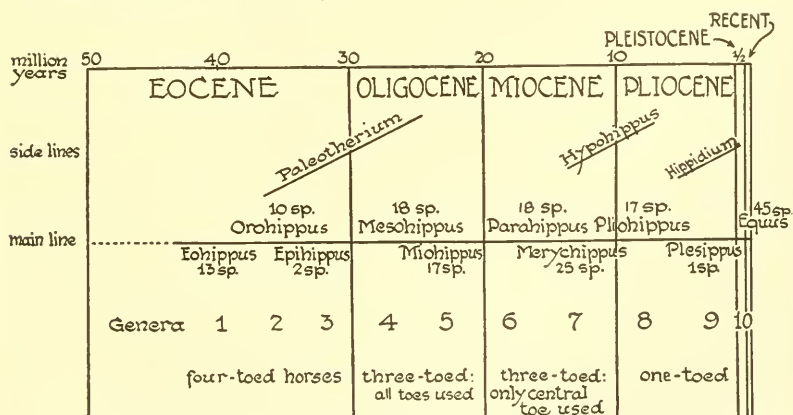
It would be quite as impossible to describe Niagara Falls without mentioning either water or honeymooners, as to write about evidences of evolution from fossils without citing the remarkable known history of the horse. Everyone is led to refer to this famous pedigree, extending back for something like forty million years, because it furnishes a perfect and well-authenticated demonstration of evolution.

The earliest known "horse" was *Eohippus*, of which thirteen species have been identified from the Eocene period. A full grown *Eohippus* was scarcely more than a foot high. It had four toes and a remnant of a fifth on each front foot, with three toes and parts of a first and fifth on each hind foot. These feet were well adapted for living on the soft ground of forest areas. The teeth of *Eohippus* were piglike in character and not at all like the highly modified teeth of modern horses. In fact, during Eocene times all the mammals were in a decidedly primitive stage, not yet having become differentiated into carnivores and herbivores, with corresponding modifications of their teeth and general structure.

If we now leap the intervening years and come down to the modern horse, *Equus*, we find a very different animal. Its adult size is much larger. It is the only quadruped which, like a toe-dancer, stands upon a shoelike hoof at the tip of a single toe on each foot with its heel high off the ground. It is adapted for rapid flight over open plains, for, since the days of *Eohippus*, carnivorous schoolmasters have appeared to teach it how to run for its life. Its teeth are unique. The molars are all practically alike, with high crowns constructed in such a way, with hard enamel and softer dentine side by side, that these substances wear away unequally, thus always leaving sharp grinding enamel surfaces. Moreover, its teeth continue to grow for some years, instead of attaining maturity early in life, and so are enabled to keep up the life long grind to which they are subjected.

There are forty-five fossil species of *Equus*, and seven wild species now living in Asia and Africa, from which domesticated horses and donkeys have been derived. Between the extremes of Eocene *Eohippus* and modern horses, eight other genera have been found, containing over one hundred species, and forming a continuous series with no gaps of importance. The arrangement of this series, and the approximate duration in time of each type, is shown in the accompanying table. In addition to the main line that eventuated in *Equus*, there have been various side lines which became extinct.

The original home of *Eohippus*, and other genera of fossil horses, was North America, and here for millions of years they worked out their evolutionary salvation. In Pleistocene times, they made repeated migrations back and forth across the Bering Sea bridge to Eurasia and Africa, where their descendants, the wild asses and zebras, carry on today. Meanwhile, all the horses of North America became extinct, not suddenly but gradually over a stretch of thousands of years. What caused their extinction is unknown. Perhaps it was the Pleistocene glaciers, or it may be that they were finally wiped out by their carnivorous enemies. The suggestion has even been made that the deadly *tsetse flies*, fossils of which have been found in the Florissant shales of Colorado, might have caused their downfall. These villainous flies, with the aid of parasitic protozoans which they transfer to mammalian hosts, have made it impossible for any except native cattle and horses to live in considerable river bottom areas of Africa today.



The 40,000,000 year old pedigree of the horse, involving in a direct line at least ten genera and over one hundred species.

The final episode in equine history occurred in very recent times, even as late as after Adam's ancestors had become human beings and had passed through a series of many civilizations that arose and fell. Then, preceding the comparatively recent Christian era, there came long dark ages until yesterday, in the seventeenth century, adventurous Spaniards brought to South America domesticated descendants of the European branch of this long, royal equine line. Some of these much traveled horses, being set free, "went native," and became the wild mustangs and broncos which spread from South America, and finally came to reoccupy their ancestral plains in North America. Thousands of skeletons of fossil horses all along the evolutionary line have been discovered, and may be seen in various museums. Their sequence is so plain that even the uninitiated can understand it and be convinced of the truth. When once this documentary evidence is realized, the fact of evolution is established beyond any doubt.

A common difficulty in accepting the evidences of organic evolution is inability to appreciate the length of time that it has taken. It never could have come about within a few thousand years. How ridiculous it is to expect anything like a laboratory demonstration of an accomplishment which has taken millions of years to effect! The geologist, however, presents us with all the years we could possibly need to enable us to allow for the slow processes of evolution; so many, in fact, that we grow intellectually footsore and weary traveling backward in time. The story of the horse, for example, occupied only a part of the Cenozoic era, or about one tenth of the time since the dawn of the Paleozoic era in which the general record of fossils begins. The fact that at this early time all the large groups of animals except vertebrates were represented in great diversity makes it reasonable to suppose that evolution of organic forms did not start then, but had already been going on long enough to lead up to the Paleozoic differentiation of types. It should be remembered that only in sedimentary rocks, the earliest of which belong to the Paleozoic era, are fossil epitaphs recorded. Many lines die out. Even the horse is on its last legs in an evolutionary sense, with only a paltry half dozen or so living species left out of all the past.

Some of the inescapable conclusions of the occurrence of evolution that are reached by an examination of the evidence from fossils are: (a) that there is a general increase in complexity of organisms as time

goes on ; (b) that organic forms are derived from preceding forms ; (c) that connecting links, beyond Darwin's fondest dreams, are now known ; (d) that the rate of evolution varies in different kinds of animals and plants ; (e) that when a species is once extinct, there is no reappearance of it.

A table, indicating the rise and expansion of typical groups of organisms, is shown in the accompanying record of geological chronology.

TABLE OF GEOLOGICAL CHRONOLOGY (Modified from Lull)

ERAS	PERIODS	ADVANCES IN LIFE	DOMINANT LIFE
Psychozoic	Recent (Post-glacial)	Era of mental life	Man
Cenozoic	Pleistocene (Glacial period)	Extinction of great mammals	Mammals
	Pliocene	Origin of man	
	Miocene	Culmination of mammals	
	Oligocene	Rise of higher mammals	
	Eocene	Rise of horses	
	Paleocene	Dominance of archaic mammals	
Mesozoic	Cretaceous	Extinction of great reptiles Rise of flowering plants	Reptiles
	Jurassic	Rise of birds and pterodactyls	
	Triassic	Rise of dinosaurs	
Paleozoic	Permian (Glacial period)	Rise of ammonites Last of trilobites	Amphibians
	Carboniferous	Rise of reptiles and insects Abundant land plants	Fishes
	Devonian	Rise of amphibians First land flora Ganoid fishes Corals and brachiopods	
	Silurian	Rise of lung fishes First air-breathers	
	Ordovician	Land plants and corals Armored fishes	
	Cambrian	Rise of molluscs Dominance of trilobites First known marine faunas	Higher shelled invertebrates
Proterozoic		Evidences of life scanty	Shell-less invertebrates
Archeozoic			Unicellular organisms

Evidence from Serology

When serum from human blood is injected at repeated intervals into a rabbit, the rabbit eventually develops *antibodies* and becomes sensitized to human blood. When the blood thus prepared is added to human blood, it produces a precipitate, a chemical change that does not occur if it is added to the blood of other animals. Unsensitized rabbit blood does not react to human blood. Rabbit blood can also be sensitized to horse serum, or to that of other animals such as the pig or fowl.

Such blood tests constitute a chemical method which enables the experimenter to determine whether or not a specimen of unknown blood is human, a technique that has proved very useful to the criminologist. In Germany blood tests have even been employed to determine the composition of suspected sausages.

By this method also the degrees of relationship between different animals can be determined. In the case of man, for example, when human-sensitized rabbit blood is added to that of anthropoid apes, the precipitation is almost as complete as with human blood. The reaction occurs in diminishing degree with Old World catarrhine monkeys, and still less with New World, long-tailed platyrrhine monkeys. It does not react in any appreciable degree with the blood of lemurs. This is in confirmation of anatomical and embryological evidence that the order of relationship among primates is man, apes, Old World monkeys, New World monkeys, and lemurs.

Rabbit blood sensitized to horse serum will react against the blood of a zebra, but less positively than to horse blood. By similar blood tests it is shown that whales are more akin to ungulates than to carnivores, that birds are closer to turtles than to lizards, and that the horseshoe crab *Limulus*, as already mentioned, is more of a scorpion or spider than it is a crab, which it externally resembles.

Evidence from Human Interference

The part man has played in directing the course of evolution is apparent in domesticated animals and plants, which often differ to a remarkable degree from wild ancestral forms, as a visit to a flower, dog, or poultry show demonstrates.

What man has done has not been creative but selective. He has employed neither laws nor methods which were not already in operation. Nature has furnished the plastic variable organisms, and man

has simply picked out and fostered those forms that have suited his purpose. If man, during the comparatively short time he has been an actor on the evolutionary stage, has been able to bring about such considerable changes in the population of the earth as is shown by domesticated animals and plants, it appears reasonable to suppose that "Mother Nature," in the enormous span of time which has been available for her experiments, would certainly be able, without human help, to have something to show in the way of evolution. The origin of some domestic races, such as maize, is quite lost in antiquity, but the wild forebears of most domestic forms are known. It is quite well established that the numerous varieties of poultry came from two original stocks, the jungle-fowl of India and the Malayan *azeel* fowl. The many kinds of pigeons — fantails, barbs, carriers, pouters, tumblers, and others — all came from an original single stock, namely, the wild rock pigeon. Pigs, sheep, cattle, horses, rabbits, guinea pigs, roses, forage plants, all trace their ancestry to wild forms. From the plastic wolflike ancestor of the dog has been evolved by the selective hand of man a most remarkable array of descendants. Think of great danes and pomeranians; long-nosed collies and snuffling pekinese; waddling bowlegged dachshunds and dainty dancing black-and-tans; woolly poodles and Mexican hairless dogs; spindle-legged greyhounds with sharp projecting features and stocky bulldogs with faces pushed in, and all the other kinds of dogs!

In many cases domesticated forms of living creatures could not survive in nature, since man has picked out different qualities than impartial nature would have selected. Someone has said, "the best bred hog can only grunt, and snooze, and die. The prairie rooter of a hundred years ago had more wit than all the Chester-Whites and Poland-Chinas of today."

Another fruitful line of human interference with evolutionary processes is that of experimental breeding, which has come to flower in the last forty years since some knowledge of the hereditary laws, furnished by Mendelism, has made it possible. This is not the place to explain what is involved in Mendelism (see XXII), except to say that it has to do with the controlled combination of hereditary lines which may result in evolutionary changes in organisms. If what man can accomplish rather abruptly by controlled matings can also take place in nature where promiscuous matings occur, then a great side light is thrown upon evolution.

Huxley once said that he "believed in justification not by faith but by experiment." In 1904 the Carnegie Institution of Washington, in order to make possible programs of scientific research looking far into the future, established at Cold Spring Harbor, Long Island, New York, a department under the significant title of EXPERIMENTAL EVOLUTION. This more recently has been renamed the DEPARTMENT OF GENETICS, since it was realized that controlled hybridization furnishes the most practical line of approach to the larger problem of evolution. What has already been accomplished by the remarkable staff of scientists at this unique station is a story of world-wide interest. It is a very good sign that intellectual curiosity does not let us rest simply with the evident conclusion that evolution of organic life *has occurred* in the past, but that it seeks to go further and tries to find out *how* evolution actually may come about.

The Environmental Theory of Lamarck

In the stormy days following the French Revolution, a famous Frenchman, with his head in the clouds above the turmoil of human history, brought out a book in which appeared the first attempt to explain *how evolution occurred*. This was Jean Baptiste Lamarck (1744-1829), whose book, *La Philosophie Zoologique*, appeared in 1809, the year Charles Darwin was born.

Lamarck was the eleventh child of his parents. When a young man, he ran away from the Jesuit College, where he was in training for the priesthood, to become a soldier in the French army. He distinguished himself for bravery on the field of battle, was disabled for further military service, and returned to scholarly pursuits. Devoting himself to botanical studies, he published important books in this field, and was also instrumental in establishing the famous *Jardin des Plantes* in Paris. In 1794, he was appointed to a chair of Invertebrate Zoology in this Institution at the age of fifty years, deserting botany to become a zoologist. His extensive observations in zoology led him to formulate his theory of evolution, at a time when everyone, including his influential fellow countryman, Georges Cuvier (1769-1832), "Father of Comparative Anatomy," held to the Linnaean idea of the constancy and independence of miraculously created species.

Lamarck's conception of the transformation of species may be thought of as standing on three legs: the molding effects of environment; the results of use and disuse; and lastly, an inner urge

or desire on the part of the organism to meet new conditions. The changes wrought by these means during the lifetime of the individual, he postulated, were then handed on through heredity to following generations. The latter assumption turned out to be a weak link in the chain.

There is plenty of evidence that environment, directly in the case of plants and indirectly through the nervous system in animals, does cause modification in the structure and behavior of animals and plants. Arctic animals, for example, develop a thick pelt, and wind-swept trees grow in a leaning attitude in accordance with prevailing winds. There is no doubt, either, of the truth of his second assumption. Use does increase, and disuse decrease, the development of muscles, as every athlete knows. The lungs of opera singers become enlarged, while unused organs in general tend to diminish.

The third postulate in his theory is not so obvious, and Lamarck himself did not stress it. According to this idea, which Lamarck's opponents made ridiculous, the desire of the ancestral deer, for example, to browse on leaves higher up off the ground caused it to stretch its neck until, after some generations of stretching, it became a giraffe. It goes without saying that plants, lacking the mechanism of a nervous system through which to express "desires," are excluded from this method of attaining evolutionary ends.

There is no doubt, however, that certain changes during the lifetime of the individual are everywhere brought about by environmental influences and the effects of use and disuse. All such evidence would offer an obvious explanation of the method of evolution if only there was assurance that during the lifetime of the individual acquisitions are passed on. Lamarck did not question that this was so, nor did his contemporaries. It remained for August Weismann (1834-1914) to point out many years later the improbability of the "inheritance of acquired characters." The great service of Lamarck was to overthrow the old idea of the fixity of species, and to suggest a reasonable hypothesis concerning the origin of variations, which must be the point of departure for every theory of evolution.

Following Lamarck's work there were three avenues open to the seeker after truth about evolution: (a) to retain belief with Linnaeus and Cuvier in the fixity of species, with no evolutionary transformation; (b) to accept Lamarck's theory of the causes of variation and the inheritance of acquired characteristics; or (c) to find some other explanation of how evolution came about.

The Natural Selection Theory of Darwin

The *Theory of Natural Selection* was arrived at independently and simultaneously by Charles Darwin (1809-1873) and Alfred Russell Wallace (1822-1913). It is greatly to the honor of these two gentlemen that neither one jealously claimed priority for the idea. They remained throughout life friends rather than rivals. Darwin's elaboration was the more exhaustive of the two, and consequently his name is more often the one associated with the theory.

When a young man, Darwin, as naturalist on board the *Beagle*, which was employed by the British Government in making extensive surveys for navigation, spent five years "seeing the world." For the next twenty years he mulled over what he had seen, adding to it by exhaustive study and experiment, before he was ready to publish his results. *The Origin of Species* appeared in November, 1859, and the entire first edition was sold out on the first day. There is no doubt that it is the most famous scientific book of the nineteenth century. It has gone through many subsequent editions and has been translated into many languages. It is the parent of whole libraries of intellectual children. The thoroughness with which the work was done, and the restraint and caution employed, explains why the edifice of Natural Selection there set forth has withstood the battering storms of controversy during subsequent years. That part of the theory which has been modified necessarily to make it square today with the advance of biological knowledge has to do largely with the nature of variations and the mechanism of heredity. The central thesis stands.

Darwin was impressed with the effectiveness of human selection in the formation of domestic species, and extended this idea to include nature as the selective agent instead of man. The essentials of Darwin's theory are as follows: (a) variation occurs in all organisms; (b) universal prodigality of reproduction tends to overpopulation; (c) a struggle for existence results, which tends to check overpopulation; (d) survival of the best adapted to survive, and the elimination of the unsuccessful, follows the struggle for existence; (e) the life-saving qualities so selected by nature are transmitted to the offspring and become the cumulative heritage of the race; (f) hereditary characteristics acquired through natural selection are prevented by isolation, either geographical or physiological, from cancellation or

swamping with parent stocks; and finally (*g*) result in a NEWLY ADAPTED SPECIES. Some brief expansion of these six points follows.

Variation

Darwin started out with the universally observable fact of variation among organisms *as an axiom*. Unlike Lamarck, he did not make any particular attempt to find out the underlying causes of variation. He pointed out, however, that even things so apparently alike to the casual observer as a flock of sheep invariably reveal individual differences to the shepherd who knows his sheep. Each structural feature of an organism may exhibit variation, making an enormous range of variability possible among a group of similar individuals. Variations are of different kinds so far as they affect the survival of individuals. Some are useful in survival, some are indifferent, and some are either harmful or even lethal. "There is none perfect, no not one."

Organisms do not vary *in order to* become better adapted to their environment, as Lamarck assumed in the case of his fantastic deer that became a giraffe, but they may be better adapted to the environment *as a result* of the occurrence of variation.

Overpopulation

Both Darwin and Wallace were much impressed by the writings of an English clergyman, Thomas Malthus (1766-1834). This mathematically inclined gentleman, who lived in the prolific days of large families, was much concerned by the fact that mankind was apparently increasing faster than the food supply. Darwin goes to considerable length to point out that every organism produces many more offspring than can possibly grow to maturity, even under the most favorable conditions. A single toadstool, for example, may easily produce a million spores, while a termite queen can furnish an average of an egg a minute for a year at a time. Even the animals breeding most slowly would require, if all their young succeeded in becoming adult, only a few centuries of unlimited geological time to overrun the entire world. Yet, in general, organisms do no more than hold their own year after year, except occasionally when the "balance of nature" gets upset, and plagues of grasshoppers, starlings, weeds, gypsy moths, and what not, flare up locally for a limited period.

Struggle for Existence

As a consequence of the prodigality of overproduction, there follows a struggle for existence, which is simply the result of an effort on the part of every creature to live and leave descendants. This struggle may be against environmental conditions, between individuals of the same species, or between individuals of different species.

Bumpus describes a case of the first sort in which some sixty English sparrows out of a colony wintering in a church belfry perished in a sleet storm. When they were statistically compared with an equal number of survivors with respect to ten measurable anatomical features, it was found that those which perished in the struggle for existence under the adverse environment of the sleet storm were the most variable ones at either extreme, that is, the anatomical geniuses and dullards, while the conservative average ones survived.

An example of the second kind of struggle for existence is found in the competition between a parent plant and its offspring for moisture, standing room, air, light, and nutriment. Most plants have well-known devices for lessening this competition by scattering their seeds outside the immediate parental environment. Among animals, as also even among humans, there are all sorts of inducements to make the young shift for themselves and not to continue to live off their parents.

The cobweb house-spider, *Theridium*, hangs up a little pear-shaped woven bag with several dozen tiny eggs in it. When these hatch out within the bag, there is nothing for the young spiders to eat except brothers and sisters, which they proceed to devour. The first ones to hatch have a decided advantage, and finally, only two or three of the whole lot triumphantly emerge out of the woven bag. The worse a spider is ethically, according to human standards, the better that spider is as a spider. It is thus seen that not only the movements of the heavenly bodies are subject to Einstein's law of relativity, but that ethics are also.

There is finally an age-long struggle also between carnivores and their prey, and between different organisms of all sorts for food, and for whatever else is necessary for the maintenance of life. It is not all competition, however, since co-operation frequently enters into the struggle for existence, as is instanced by the mutual protection secured in flocks and herds. This gives an altruistic touch to the picture.

Moreover, the struggle for existence is not necessarily a cruel, bloody, hand-to-hand encounter. On the contrary it is unconscious in most cases, and when death comes it is usually during the earlier stages of life, painless and without worrisome premonition or warning. Nature's ways are simply the *way things are*, wholesome and innocent, and not tinged either with the bitterness of human hate or with sweet sentimentality. It is wise to remember that most of the supposed joys and sorrows of animals and plants are quite beyond our ken.

Survival and Elimination

Left to herself, Nature either "mends or ends." The result of the struggle for existence is, in most instances, the survival of the fittest, that is, of those best adapted to cope with the circumstances to which they are subjected. Stated another way, it is the *elimination of the unfit*, namely, those that fail to make good. Both are processes that tend to provide better ancestors for succeeding generations.

It is not always the "fittest" by any means that survive, for the best do not invariably succeed in living. Sometimes it is the lucky ones rather than the best. When a whalebone whale, for example, strains out a million microscopic crustaceans from the sea-water in taking one gigantic swallow of the animated sea-soup which constitutes its food, those that escape are not necessarily the best fitted to survive.

The more we examine details, however, the fewer are the cases in which there does not appear some factor of structure or behavior that plays a determining part in survival or elimination. Sudden environmental changes usually result disastrously in the extinction of organisms, while gradual changes tend to allow latent adaptive possibilities in plastic plants and animals to come into expression.

Specialization is hazardous, because, although by means of it an organism may become better fitted to one set of conditions, it results in a loss of plasticity and of the organic resources necessary to meet changes successfully. Better adaptation means having more resources for survival. The great group of insects, for example, have gained their dominance in the animal world, as demonstrated by their great numbers and diversity, partly, without doubt, because of their small size, short life-cycle, and infinite variety, all factors that have aided them to survive.

Inheritance

New species are not formed by survival alone. They are only *sorted out* in that way from variations that have appeared.

After potentially better parents have been "selected" through the processes of the survival of the fittest and the elimination of the unfit, then some effective way must be found for the transmission of these life-winning qualities to the next generation, or there can be no evolution of the race. Here enters again the old question of whether the cumulative acquisitions of a lifetime are transmissible, as Lamarck held, or whether there is some other possible way to get from Ameba to man.

Although no doubt Darwin sensed something of the uncertain nature of acquired characteristics, he did not deny their adequacy as a means of evolutionary advance, and in that regard Darwinism offers no improvement over Lamarckianism. What he did do was to emphasize the importance of inborn rather than environmental characteristics, as of greater value in the selective process. It is not so much what an animal becomes or accomplishes in its lifetime that is of hereditary importance to the offspring, as *what it has within itself to accomplish*. Among human kind, success in life may be more of a family affair (heredity) than a matter of education (environment and training). Inherent possibilities, whatever their origin, are plainly transmissible, and furnish the needful material on which selection may act for cumulative improvement.

Darwin tried to imagine how acquired characters could become inherent, and so transmissible along with other hereditary characteristics. To this end he elaborated his supplementary *pangenesis hypothesis*, which briefly is that specific determiners, or *pangenes*, are formed by every part of the body. These pangenes, like instructed delegates representing various constituencies, collect together to make up the germ cells from which a new individual arises. When such germ cells unfold their possibilities in development, every part of the parental body, including acquired characters, is represented, and consequently may reappear in the new individual.

Pangenesis was a brilliant attempt to strengthen the weakest link in the chain of explanation of how natural selection might give rise to new species. There are too many *ifs*, however, to this delightfully simple hypothesis. It must be remembered that it was suggested before the astonishing story of the chromosomes was known, and

before Mendel and his followers had laid bare the essential mechanism of heredity. In a later paragraph, reference will be made to how Darwin's great German disciple, Weismann, came to the rescue and made the hypothesis of pangenesis unnecessary.

Isolation

"The nearest relative of any species is not to be found in the same area, nor in a far distant area, but in a nearby area, separated from it by barriers." This is the *Law of Isolation* as formulated by David Starr Jordan. Unless some sort of isolation prevents or minimizes the swamping effect of promiscuous interbreeding, a newly "selected" species has difficulty in maintaining its independence.

There are first of all geographic barriers that lead to isolation, as, for example, the water barrier when *continental islands* are cut off from the mainland. In such cases, since the island types can no longer breed with the continental forms from which they arose, there is furnished an opportunity, due to isolation, for them to maintain the modifications which make them different species. *Oceanic islands* also illustrate the part isolation plays in establishing new species. For instance, the volcanic island of Oahu, on which Honolulu is situated, is fluted with valleys as the result of erosion, and each valley, as Gulick has shown, has its own peculiar species of land snail of the genus *Achatinella*. These snails live in trees and are isolated, each species in its own valley, because the mountainous ridges between the valleys furnish a barrier to their intermingling with each other.

In addition to geographic barriers there are *biological barriers* that provide isolation for newly formed species, protecting them from the leveling effects of mixture with the parental stocks. Plants, for example, may maintain their individuality, even while remaining in the same habitat with contaminating relatives, by practicing self-fertilization, or by establishing a different period of sexual maturity.

There are a dozen different species of albatross in the Southern Hemisphere which mingle freely throughout the whole range of their wanderings except during the breeding season, when the members of each species are segregated in their own quarters to reproduce. This behavior is true of migrating birds in general so that, so far as breeding goes, there is virtual isolation among them.

Dr. Vernon L. Kellogg, an authority on bird-lice (Mallophaga), is acquainted with several hundred species that live parasitically among the feathers of birds. He finds that nearly every kind of bird entertains its own particular species of bird-lice. Since birds of different species in their aerial activities do not often come into bodily contact, these wingless bird-lice are isolated, as if on an island, and each species is passed around among nest mates of bird hosts of one kind. This peculiar type of isolation on specific hosts helps to explain why so many different sorts of Mallophaga have evolved and maintained their distinctive differences.

The Mutation Theory of DeVries

Darwin devoted a large portion of *The Origin of Species* to a discussion of anticipated objections to the theory of natural selection. An attempt to review these controversial matters is aside from the purpose of this book. They form a pile of straw that has been thoroughly threshed over, not only by Darwin himself but by biologists generally. Suffice it to say that, after all the objections to this theory have been considered, Darwin's contribution to the fundamental problem of evolution remains an enduring monument to his genius, the influence of which extends far beyond the realm of biology.

One of the difficulties that has often been emphasized has to do with variations, which are the indispensable materials for selection to act upon. The kind of variation on which Darwin depended was the minute modifications everywhere evident. Natural selection does not satisfactorily explain how such slight variations can become life-determining. In order to assume importance in the survival of the individuals possessing them, that is, to become of selective value, these slight variations must accumulate and increase until they acquire a life-and-death significance in the struggle for existence. The greenness of a katydid, for example, is a life-saving feature which renders its possessor largely invisible to its bird enemies, against a background of green leaves. A slight departure towards greenness from the ancestral conspicuous brown color of the species would be of no use in concealment. Natural selection cannot take hold until there is enough greenness developed to provide safety by concealment. One suggestion is that useless variations are often correlated with useful ones and so are rescued from oblivion, just as in a "landslide" during a political election many insignificant minor officials arrive in office on the coat-tails of the real winner.

Another theoretical escape from the dilemma is furnished by the assumption that the variations employed in survival are not all made out of accumulations of the useless sort, which are often transitory effects of the environment and not heritable, but are a particular kind of variation that is of hereditary significance from the start. Evidence of the existence of such a distinctive kind of germinal variation, whose transmissibility is not questionable, has been furnished by the Dutch botanist Hugo DeVries (1846-1935) in his book entitled *Die Mutationstheorie*. By chance DeVries discovered among some wild evening primroses, *Oenothera*, certain individuals so decidedly different from the original type that they would be regarded by a botanist as distinct species if the history of their origin was not known. There was evidence that these new forms did not evolve gradually, but that they appeared suddenly with no warning of imminent change. Moreover, when isolated they reproduced their distinctive characteristics. Variations of this kind *that breed true* DeVries called *mutations*.

It is now known that the occurrence of mutations is widespread among both plants and animals. Several hundred distinct mutations, for example, have been described from the much-studied fruit fly, *Drosophila*, alone. Mutations may be useless or useful in survival, but in any case they are heritable and thus furnish raw materials for the selection mill. In other words, all mutations must still run the gauntlet of natural selection.

DeVries' theory made it clear that it is not necessary to wait for the slow accretions of insignificant useless chance variations to provide characteristics of selective value, since mutations furnish the necessary materials which evolution demands, ready made and transmissible. Thus, existing organisms are to be regarded as the sum of the mutations that have survived since the dawn of life.

The reality of mutations has been amply demonstrated. The *causes* of this type of variation, however, are still a matter for further study and investigation, in which considerable progress has already been made. It is likely, furthermore, that the mutations of DeVries do not represent the introduction of something entirely new, but rather a new combination of characters already present. The great service of DeVries' work lies in the fact that the explanation of the method of evolution has been shifted by means of it from the unscientific field of argument to the more scientific and dependable field of experimentation.

Germplasm Theory of Weismann

August Weismann (1834–1914), who was an ardent supporter of Darwin, went straight at the heart of another difficulty, which not only Darwin himself but also Lamarck had encountered, namely, the problem of the *manner* in which inheritance takes place.

A critical examination of available facts convinced Weismann that only inborn characteristics are handed on from generation to generation, and that peculiarities picked up by parents during their lifetime come to an end with the death of the individual. This led to the formulation of the *Germplasm Theory*, namely, that the germ cells from which the individuals arise, and which are the bearers of the hereditary possibilities, are quite different from the innumerable transitory cells that make up the rest of the body. According to Weismann's theory, germinal material forms a continuous chain, from which in successive generations individual organisms temporarily develop. The germinal material, although it is subject to death with the mortal body of the organism, is potentially immortal, because in the process of reproduction it may continue from generation to generation.

This conception led Weismann to question the possibility of the transmission of bodily acquisitions from one generation to another, since the avenue of transmission is by way of the germinal stream and not, as popularly supposed, from one body to another. The body is simply the visible expression of the germinal characters handed on from its ancestry, and for which it serves only as a temporary carrier. The body of the individual does not produce the germ cells, as Darwin's hypothesis of pangenesis assumed, but *the germ cells produce the body*. It must be admitted that Weismann did a thorough job in discrediting the supposed inheritance of acquired characters, for today biologists are quite generally agreed that such inheritance does not occur, or if it does, only to an insignificant extent. The court of last resort for those who are unconvinced is appeal to further facts, to be obtained by decisive experimentation. The value of Weismann's speculative thought was largely due to the fact that it stimulated further research and discovery.

The whole course of evolution thus finally resolves itself into what occurs in the unseen germplasm, as opposed to what takes place in the visible parts of the body. Selection of variations of any sort is of importance only when those bodily characters are recognized as

carriers of hereditary qualities that have come down the long ancestral line through the continuous germinal stream.

Other Theories

It would be going too far afield to attempt here to review all of the other theories that have been advanced to account for evolution in whole or in part. Some of these are subsidiary to the theory of natural selection, as, for instance, Darwin's own theory of *Pangensis*, already mentioned, and also his theory of *Sexual Selection*.

Perhaps the largest group of alternative theories of descent are those which center around the idea of *Orthogenesis*. These theories hold that variation is not qualitative and random in character in every direction, but quantitative, that is, either plus or minus modifications and in one direction only. According to this idea variations form a determinative series that goes forwards or backwards relentlessly, with little reference to adaptation and in spite of environmental influences. Overspecialization, as in the case of the gigantic antlers of the extinct Irish elk, finds in orthogenesis an easy explanation, for cumulative variations of this kind may gain such headway in one direction that they overshoot the goal and lead to eventual destruction.

Weismann in his supplementary theory of *Germinal Selection* and Wilhelm Roux (1850-1924) with his *Kampf der Teile*, or struggle between the parts, have transferred the struggle for existence from individuals to the component parts of individuals, while various vitalistic attempts, like Bergson's *Élan Vital*, and George Bernard Shaw's *Life Force*, have been made, which dodge the whole issue by invoking some mystical agency that is beyond the reach of scientific testing by experiment.

Conclusion

Darwin's great service was that he formulated a plausible explanation for the theory of descent which did not beg the whole question by resorting to the supernatural. "Mother Nature" is not a directive personality substituted by "ungodly scientists" for the supernatural Creator of all things. There is no more personality in natural selection than there is in the wind, which "selects" the grain from the chaff. Nor is there necessarily any more design, any more purpose or moral bearing to natural selection than there is in the action of the law of gravity, or in the shaping of water-worn rocks by the surf

at the seashore. Natural factors that can be observed and measured, and whose effects can be predicted, are all that are involved.

Truth-seekers do well to exhaust first of all what may be proven or disproven by observation as well as by experiment with natural things and processes that are within reach, before appealing to the supernatural, which lies beyond the realm of science. Natural law is an observed and verifiable sequence of events that is dependable and makes the prediction of future events possible or probable. For example, under the same atmospheric pressure water always boils at the same temperature, you can depend on it. On the other hand, the supernatural is an interference with natural sequences, and is neither predictable nor dependable.

It is not the scientific way of disposing of difficulties to shake the head and look wise, or to call in unknown supernatural aids, as long as unexhausted natural resources remain at hand. Dr. W. E. Ritter's wise advice to scientists might well be taken to heart by everyone, "Investigate things *as they are*, not as they *might be*, or *ought to be*." Darwin did just this, and consequently his concept of the "*Origin of Species by Means of Natural Selection*" is much more than an attempted explanation of how evolution came about. It is a model exposition of the scientific method of thinking, which finds universal application in all fields of human endeavor. Darwin and Abraham Lincoln were born on the same day. Both were great emancipators in different fields. That the theory of natural selection falls short in certain particulars is not important. It has served its purpose in stimulating and giving direction to further investigation, which is what makes life worth living. Any theory is like a temporary scaffolding to be discarded after the building is erected, for if it is still retained intact, it may obscure the building itself.

Robert Boyle, the physicist (1627-1691), once said with reference to theories in general,

"Having met with many things for which I can assign no possible cause, and with some for which many different ones might be alleged, I dare speak positively and confidently of very few things except of matters of fact."

William Harvey (1578-1657), who discovered the circulation of the blood, also summed up the scientific attitude in these words :

"Some . . . persons vainly seek by dialectics and far-fetched arguments, either to upset or to establish things that are only to be founded on anatomical demonstration, and believed on the evidence of the senses. He

who truly desires to be informed on the question at hand, and whether the facts alleged be sensible, visible, or not, must be bound either to look for himself or take on trust the conclusions to which they have come who have looked, and indeed there is no higher method of attaining to assurance and certainty."

In conclusion this whole section of the theoretical aspects of biology is well epitomized by Dr. A. D. Mead.

"The centuries of biological research could not change the order of nature. The increased knowledge may not even mean greater wisdom in handling knowledge. It may not, perhaps, though it ought to, make men more sensitive to the wonder of it all. But it has thoroughly involved man in the laws that govern plants and animals in general, and has deeply altered our conception of what those laws are."

SUGGESTED READINGS

Kellogg, V. L., *Evolution*, D. Appleton Co., 1924.

A popular and very readable account of the history and evidence of evolution.

Kerr, J. G., *Evolution*, The Macmillan Co., 1926.

The book is written for beginners, who will find the author's reasoning easy to follow and understand.

Lull, R. S., *Ways of Life*, Harper & Bros., 1925.

An excellent book for the layman who wishes a clear, concise statement of the scientific data relating to the evidences of evolution and the origin and history of living things.

Parker, G. H., *What Evolution Is*, Harvard University Press, 1925.

A clear, brief outline.

Ward, H., *Evolution for John Doe*, Bobbs-Merrill Co., 1925.

Non-technical, as readable and interesting as a detective story.

XXIII

THAT ANIMAL, MAN (ANTHROPOLOGY)

PREVIEW. The process of becoming human · Our primate cousins · The downward ascent of man · The consequences of an upright life · The greatest wonder in the world · Flint and metal history · Getting the upper hand of things · Gaining ideas and passing them on · Skeletons in the Pleistocene ice chest: Java man; Heidelberg jaw; Charles Darwin's neighbor; the first lady of China; the Neanderthals; wild horse hunters; reindeer hunters · Races · Passing muster · The biological Garden of Eden · Suggested readings.

PREVIEW

"My favorite, and I might say my only study, is man."

— GEORGE BORROW.

If a board sidewalk belted the earth at the equator, and the entire present human population, estimated at 1,700,000,000, should fall into a lockstep procession on it, the line would girdle the globe some seventy times. The sidewalk would need to be at least one hundred and fifty feet wide in order to allow the procession to move, and even then there would be considerable shoving and crowding, and countless toes would be stepped on.

In spite of the fact that mankind forms one of the most recent species to be evolved, no other animal is so widespread over the earth, and adapted to occupy successfully so many diverse habitats all the way from "Greenland's icy mountains to India's coral strand."

That man is an animal, subject to the same biological laws as other animals, was recognized in 1755 by Linnaeus (1707-1778) when he included *Homo sapiens* in his classification of animals, although without the idea of relationship, which culminated later with Darwin. Although there are countless detailed evidences of animal relationship, man is in many ways quite unique and stands head and shoulders above other animals. Man is the only animal that can make such a claim and put it in writing. No other animal can communicate abstract ideas. No other animal can measure the distance between the stars, or build a steamboat, or speak a sentence, or compose a symphony, or commit a sin and be sorry for it, or levy taxes, or take thought for the morrow, but mankind as a whole can do them all, and much besides.

The science of man is called *Anthropology*, and it might well claim our attention for more than the space which it is possible to allot to it in this book, for, as Professor Shaler (1841–1906) once wrote, “The cry of *what is man* from the Hebrew singer has been re-echoed in all ages and lands wherever men have attained the dignity of contemplation.”

The Process of Becoming Human

No one knows the total duration of life upon the earth, not even paleontologists, but evidences are unmistakable that millions of years have elapsed since the dawn of life, when animals and plants first appeared. It does not matter that the estimates of experts are at great variance. The fact remains that an enormous stretch of years was involved in the evolutionary preface to mankind.

So far as is known, man emerged from the evolutionary welter only about 500,000 years ago, although a long chain of events extending over millions of years led up to his advent. Someone has estimated that if a moving picture of the successive geological ages, in which there is a known fossil record of life, could be speeded up and compressed into a continuous show of fourteen hours beginning at 10 A.M., man would appear first on the screen about five minutes before midnight. Such a picture would begin with simple unicellular organisms, at first neither plant nor animal but gradually evolving into one or the other, and followed eventually by a multitudinous host of protozoans. These emerging, and later becoming diversified, would be seen to foretell in miniature something of future possibilities by reason of having worked out, even with a body made up of only a single cell, varieties resembling superficially Lilliputian Hydras, worms, snails, sea-urchins, crabs, and other higher forms of life. Since protozoans in reproduction habitually produce twins by the process of fission, the story continues with the rise of the long dynasty of the metazoans, or multicellular forms, that developed when protozoan twins, like “Siamese twins,” got the habit of hanging together.

Next follows the pattern of sponges, each a loosely aggregated mob of individual cells, which, as time went on, in more complicated forms higher up the scale, became organized and differentiated into orderly tissues, thus making possible the development of organs. Then coelenterates, lowly plantlike animals generally of sessile habit, gradually became free-swimming and adventurous, while their radial type of symmetry in consequence was in due time transformed into the

bilateral type, making possible the revolutionary head end. In this device a suitable home was furnished for the brain when it should appear, with exploratory sense organs near by, placed handily to best advantage for receiving impressions from the immediate surroundings. Following this by the device of metamerism, which is a division of the body into segments, primitive flatworms took on annelid characteristics, thus acquiring flexibility after the manner of a train of cars, and also gaining survival insurance against accidental loss of parts.

Locomotor legs soon came in to lift the long crawling body off the ground, thereby much lessening friction in traveling about. Legs developed joints, adding the mechanical advantage of levers. Various experiments in the number of legs were tried out with a result of increasing efficiency. Myriapods and centipedes had too many. Crustaceans began a reduction. Spiders and their allies brought the number down to eight, while the great group of insects finally settled upon six legs as the prevailing fashion. It remained for vertebrates to get along at first with only four legs, one under each corner of a horizontal body, like the legs of a table. Eventually in the case of birds and man, and some other vertebrates, only a single pair of legs remains at the end of an upright vertical body. It is likely that evolution has reached its limit with reduction to one pair of locomotor legs, since a one-legged animal would obviously be at a disadvantage. However, with these legs we have run ahead of our story.

When skeletal parts for muscular attachment first developed, making locomotor legs workable, the skeleton was an *exoskeleton* on the outside of the body. Being secreted by the underlying tissues, and consequently a dead structure unyielding and hampering to the enlarging body within, it is soon outgrown and has to be discarded, frequently at considerable peril and physiological expense, to allow for future growth. It was a great day for us when our ancestors put their skeletons inside the body and became vertebrates. The vertebrate *endoskeleton* can remain alive and continue growing, and can thus keep up with the demands of increasing body size.

Many other evolutionary experiments were tried out in the course of time, resulting in the establishment of the great major phyla of the animal kingdom, but it was the *vertebrate idea* which finally forged ahead upward toward man.

The fishes served a long apprenticeship as the lowest vertebrates, principally in the waters of the great oceans that cover most of the globe, until eventually there developed those adventurous pioneers,

the amphibians, that emerged upon land. Following this notable accomplishment, modifications and adaptations came thick and fast, or the aquatic amphibians could never have met the demands of the new land habitat and become successful settlers there. They never did make a great success of it, for the transition from water to land was so gigantic an enterprise that the poor creatures barely succeeded in entering even into the edge of the Promised Land. Consequently they have always been, and remain today, the smallest and most helpless of all the vertebrate groups, but to their glory be it said that they did mark the road and pave the way over which advancing hordes of reptilian successors were enabled to press on to greater achievements. We do not appreciate the part reptiles have played in the making of man, partly by reason of the insignificance of the reptiles living today. Only a few cold blooded crawling snakes, repulsive crocodiles, furtive lizards, and sluggish turtles are left to remind us of a reptilian aristocracy that dominated the Mesozoic world for at least ten million years, and laid the foundation for the next great stride upward. In passing, we may remind ourselves that a good deal happened during the gray Mesozoic millenniums, of which we have some few hints in the fossil remains of extinct reptiles, but we must not now be diverted from our upward quest by the stirring saga of those particular past events, marking as they did the rise and dominance of life in the Reptilian age.

There were two ways of escape out of this long-drawn-out ancient reptilian "civilization," namely, by way of the birds, or by way of the mammals. Birds do not immediately concern us in this connection, for the reason that they have sacrificed every other future prospect in becoming specialized for flight in the air, and in conquering the new aerial realm. Now at last they find themselves trapped in a lane that has no turning, and apparently without any future evolutionary outlet. They certainly did not lead the way to man.

Mammals, on the other hand, chose the better part by retaining a wider range of evolutionary resources, and meanwhile by putting off, to a considerable extent, the narrowing effects of organic specialization. The first mammals were small insignificant creatures, that were no doubt looked down upon or ignored by their reptilian contemporaries. They possessed, however, certain secrets of warm-bloodedness, prolonged parental care, and other physiological and anatomical innovations, of which the cold-blooded reptiles, with their lesser brains, never dreamed.

Changes and advances in many directions came thick and fast, once the mammalian idea was introduced. Out of all the emerging orders of mammals it was probably the *insectivores* that became the forerunners of the *primates* to which man belongs. These lowly



American Museum of Natural History

Tupaia, the tree shrew, that discovered the possibilities of tree life and thus became the probable forerunner of our arboreal ancestors.

line. Many were lost, but some have kept on in diverging pathways until today, although separated from the main highway that has led up to man. The final episode in the ascent of man concerns the story of the *primates*.

Our Primate Cousins

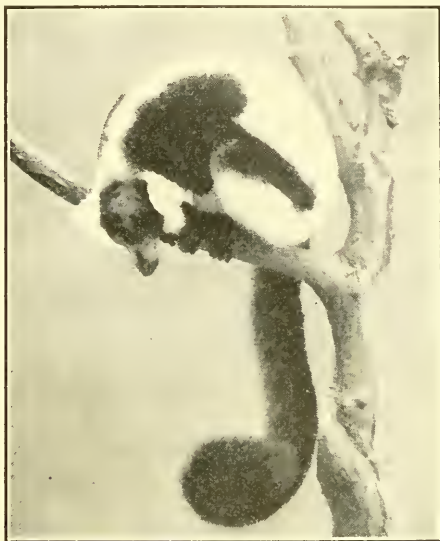
Since man is the only animal that can write a book, we find the mammalian Order to which man belongs naïvely designated as PRIMATES, or the first. If a horse could make a classification of mammals, no doubt the UNGULATES would be placed first, for they

creatures, of which the shrews, moles, and the European hedgehog are living representatives, somehow kept within the broad highway of structural generalization, not being lured into blind alleys of specialization as was the fate of the hoofed ungulates, bats, and leviathanlike whales. Certain of these insectivores, the *tree shrews*, quite unlike their modern burrowing cousins, the moles, took to arboreal life, thus gaining shelter and escaping in some degree from their terrestrial enemies. According to certain biologists, they initiated the Grand Order of the Primates, from which man has finally emerged.

So it came about that all along the long trail "from Ameba to man" there were innumerable casualties. Exploring parties left the main

have the most highly specialized feet of any vertebrate, and if whales could express themselves, they would naturally claim first place for the CETACEA, on account of their dominant size and extreme specialization. Thus are the advantages of literacy evident!

Primates include the arboreal lemurs, the curious hobgoblin *Tarsius*, monkeys, apes, and man. The greatest number of primate species are lemurs, which first appeared some three million years ago in Eocene times. According to Dr. D. G. Elliot, there are eighty-three species living to-day, mostly to be found in the forests of Madagascar, as well as many extinct species known only by their fossil remains. Living lemurs vary in size from that of a mouse to that of a cat, although the largest known extinct representative was as big as a donkey.



New York Zoological Society

A tree-dwelling lemur. What different uses for such a tail?

In habit the ghostly "wailing lemurs," which are practically confined to tree-tops, are mostly agile night-prowlers that avoid trouble by retirement during the daytime. Although their place is unmistakably among the primates, they exhibit certain anatomical features of a non-primate character, such as a low type of brain, the absence of a bony back wall to the orbits of the eyes, and a reminiscient claw on the second toe of each hind foot, while on all the other digits the claws are flattened out into primate nails. The remoteness of their relationship to other primates is further indicated by the fact that unlike other primates they have an ungulatelike placenta, possess groin-nipples as well as breast-nipples, and habitually produce several young at a time. Of particular interest to the anthropologist is the related genus of *Tarsius*, comprised of a half dozen species living in Borneo and Java. *Tarsius* is not much larger than a rat. It sits up and takes notice with its enormous eyes directed straight in front, an arrangement that is made possible by reason of the snout and jaws

being very much shortened, thus allowing the large laterally placed eyes to swing around in front into a spectroscopic position. When this curious animal wishes to look behind itself, instead of rotating the



Tarsius, the goggle-eyed lemur which arrests the attention of anthropological ancestor hunters.

eyeballs, its whole head swivels around in an alarmingly weird and dislocated manner. Members of this genus are the only primates with a single incisor tooth in each half of the lower jaw, other primates having two. Their fingers and toes are much elongated and terminate not only with nails instead of claws, but also with adhesive disks, which are very useful in arboreal life. On account of their long fingers they are decidedly hand-feeders, and are also able to take hold of objects and to bring them up close to their staring eyes for inspection, while with the hind legs, adapted for hopping and springing from limb to limb, they some-

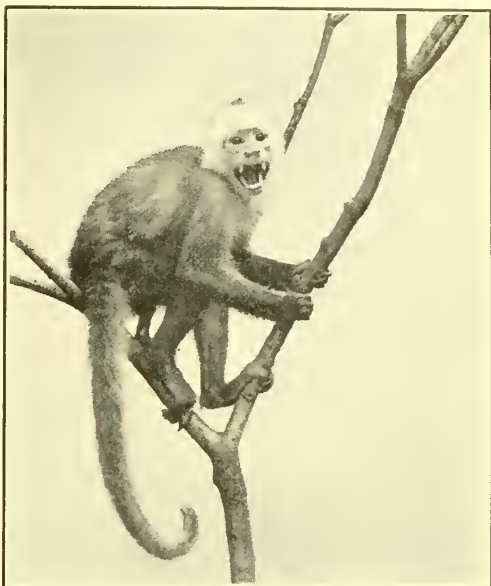
what resemble miniature kangaroos in their movements. According to some authorities, these grotesque little animals are a direct link in the evolutionary chain leading to man, while other lemurs, monkeys, and apes are held to be side deflections from the main line. The possible relationship of *Tarsius* to mankind is based mostly upon anatomical evidence, too technical to be enlarged upon here. The interested reader is urged to look beyond the pages of this book for further details.

Monkeys form two great groups, those in the New World being more primitive than their Old World relatives. The New World broad-nosed (platyrrhine) monkeys do not have an opposable thumb, but are partly compensated for this handicap by possessing a prehensile tail that serves them as a fifth hand in their aerial adventures in the tree-tops. They have a generous mouthful of thirty-six teeth. Marmosets are the smallest of the New World monkeys, and "howlers," the prima donnas of American tropical forests, are the largest, with spider monkeys, capuchins, and other species inter-

mediate in size. The Old World narrow-nosed (catarrhine) monkeys have a rather small, more or less opposable thumb and big toe, a stublike tail less useful than ornamental, and thirty-two teeth, the same number as in man. To this group belong macaques, mandrills, baboons, and proboscis monkeys, with some other species.

There are four kinds of living apes (Anthropoids), namely, gibbons, orangutans, chimpanzees, and gorillas. The anatomical gap separating these apes from monkeys may be as great, if not greater, than that between apes and man.

The *gibbons*, natives of Southeast Asia, Borneo, Sumatra, and Java, walk quite upright on the ground, often swinging along by using their arms, which are of enormous length, like a pair of crutches. They are most at home in trees, however, where they travel with astonishing rapidity and acrobatic skill. This method of locomotion is graphically described by W. T. Hornaday: ¹



New York Zoological Society

A representative of the New World long-tailed monkeys.

The gibbon "progresses by swinging himself end over end, holding by his hands while he gives his body a long swing toward another branch. His body becomes horizontal, he grasps the branch with his feet, and, letting go with his hands, swings head downward and backward, until he comes right side up again, lets go with his feet and goes flying through the air to the next branch. He grasps with his hands, swings the other end of himself forward again, and so on. . . . By this revolutionary method he goes just as well as if he had a head on each end of his body."

¹ From Hornaday, *Two Years in the Jungles*. By permission of Charles Scribner's Sons, publishers.

The short-legged *orang-utans* of Borneo and Sumatra, though larger than gibbons, are likewise denizens of tropical forests, being



more at home in the tree-tops than on the ground. They frequently build for themselves temporary nests or shelters of sticks and twigs, and exhibit an increased mental capacity over that of the gibbons.

Probably the *chimpanzees* of tropical Africa are the best known of the apes because of their teachability, and consequent exploitation on the vaudeville stage, at Hollywood, and elsewhere. In the last twenty years, Dr. Robert M. Yerkes of Yale University, with a staff of assistants, has been studying intensively the behavior of these disconcertingly "almost human" apes, maintaining for the purpose a considerable colony of them under constant observation in Florida, and another smaller group at New Haven, Connecticut. His painstaking and arduous investigations are adding very much to our accurate knowledge of the dawn of intelligence and of the ancestral sources of human behavior.



New York Zoological Society

The gibbon and chimpanzee are representatives of the apes.

The *gorillas* of Africa are the largest apes, and perhaps the least known, because of their inaccessibility and the difficulty of maintaining them in captivity. Their strength is prodigious and their courage is said to be unbounded.

Although the average body of a gorilla is perhaps twice as heavy as that of a man, the brain is only about half as large.

Of the four kinds of apes no one of them stands nearer to man than all the others in all particulars. The fact that both fossil and embryo apes present more human characteristics than either living or adult apes indicates their divergence from the main primate stem, and their cousinship to man, rather than any direct lineal relationship. No scientist assumes that man has arisen, in the course of evolution, from any contemporary species of primates. Humankind as compared with apes presents among other characteristics a less protrusible face, smaller eyebrow ridges, slighter jaws, less hairiness, larger and more elaborate brains, together with the ability to speak and to communicate abstract ideas. On the other hand, apes and man



New York Zoological Society

The gorilla and the orang-utan, members of the ape group, should be compared with those on page 538.

are subject not only to the same diseases, showing similarity in blood tests, but they also resemble each other in a great array of anatomical features. The distinctive differences between apes and man are quantitative rather than qualitative. For these reasons, if for no others, since man dwells in such an anatomical glass house, he should hesitate before throwing contemptuous stones at his anthropoid cousins.

The Downward Ascent of Man

It is related that an anxious and somewhat illiterate maiden lady once inquired at a bookstore for a copy of a book of which she had vaguely but hopefully heard, entitled *The Decent Man*. Her disappointment was great when *The Descent of Man* by Charles Darwin was finally identified as the probable book in question, confirming her suspicions that her lifelong quest was hopeless as usual. The "descent of man," however, remains another story.

Probably the ancestral home of the primates was in tropical tree-tops. The majority of living representatives of the Order still retain the same arboreal headquarters, only a few kinds, among them man, having subsequently taken to more insecure and adventurous life on the ground. As previously suggested, it was doubtless tree-shrews, in the primitive mammalian Order of the *Insectivora*, that first broke away from the terrestrial habitat of ancestral reptiles, and adventured into tree-tops. There are anatomical reasons that lead us to suspect that the tree shrews, educated in their aerial manual training school, gave rise in the course of time to lemurs and other primates. Modern representatives of the tree shrews are still to be found in the forests of Borneo. They are small, generalized, plantigrade animals with five digits on each foot, and a long pointed snout, housing well-developed organs of smell.

Arboreal life wrought profound modifications in these primate explorers of the new tree habitat. The poking insectivorous snout, with its keen sense of smell, as its usefulness off the ground was lessened, gradually retreated, while the eyes and the tactile sense, indispensable in arboreal life, came into dominance. The front legs were now lengthened and adapted for sustaining the hanging weight of the body, while the hind legs became not only organs of support, but also were fitted for springing and leaping from limb to limb. When at rest in trees, the sitting posture was naturally adopted, so that the originally horizontal quadruped became a more or less vertical animal, a change entailing a long list of further anatomical adjustments. Chief among the advantages accruing from sitting up on end was the release of the front legs from the function of support. Frogs, however, which are also famous sitters, still use their front legs for bracing support, and so gain nothing new by assuming the semi-vertical posture of contemplation. Generally speaking, the front legs of sitting primates were transformed into reaching arms with grasping

hands, whereby their surroundings could be explored and objects of interest brought up close to their sense-organs for examination. This method was a vast improvement over the necessity of moving the sense-organs, body and all, into the immediate neighborhood of objects to be examined.

As long as primates kept to the comparative security of aerial apartments in trees, they necessarily could not attain large militant size, for trees are no suitable place for heavy or bulky animals. So the time inevitably came when certain of the primates, after a long period of arboreal schooling, ventured more and more down upon the ground until finally, in the case of man, the descent was made permanent. The descent of ancestral man from an arboreal habitat, however, resolves itself after all into an evolutionary *ascent*, or step upward, for life is much more worth living on the ground than in trees. There are more enemies to combat, and more necessity and opportunity for sharpening the wits. The table also is spread with more available food, in particular a greater variety of vegetation, and, in the animal world, creepers, crawlers, burrowers, runners, jumpers, and swimmers, all good to eat, that are out of easy reach of tree-dwellers.

It was comparatively easy with increasing intelligence to make the transition from sitting in trees to walking vertically on the ground, and every human baby faithfully repeats the ancestral story by first sitting up on end before balancing on its hind legs in learning to walk.

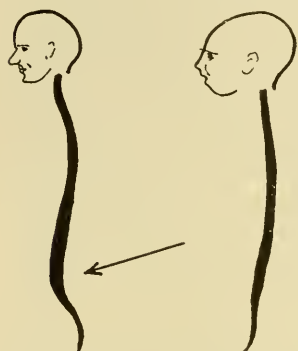
Finally, it may again be repeated that none of the primates existing today are to be regarded as directly ancestral to man, as is often popularly supposed.

The Consequences of an Upright Life

As long as the forerunner of man went about on all fours, whatever brain was present, being encased in a heavy bony skull, had to be carried out in front of the body, at considerable mechanical disadvantage. In the case of the horse, for example, a large unwieldy neck, made up of vertebrae and abundant muscles and tendons, is necessary to guy the heavy head to the long, blade-like, bony, spinous processes which stand up in a row behind. The cheek-rein of a driving harness is man's contribution to the horse's age-old problem of holding up its head.

After the upright posture was hit upon in the course of evolution, however, this particular disadvantage largely disappeared, since the increasing heaviness of the encased brain was amply provided for by poising the whole head on the top of a supporting pillar-like vertebral column.

Experiments in assuming an upright posture and in going about on the hind legs did not originate with the primates. There were Mesozoic dinosaurs, for example, that habitually reared up their gigantic bodies on end, also the whole class of birds, as well as various kinds of jumping animals such as kangaroos.



Adult

Infant

Diagrams showing the difference in the curvature of the backbone between the infant and the adult. (From Walter, *The Human Skeleton*. By permission of The Macmillan Company, publishers.)

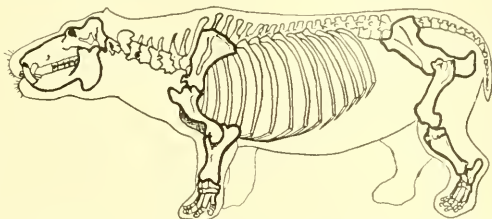
In these cases, however, while standing up, the legs are bent in a sitting attitude, with the knees projecting forward. It remained for man to become the most straight-legged upright biped of them all, and this fact has resulted in the modification of practically every part of his anatomy.

The single archlike curving backbone of a typical quadruped, from which the weight of the body hangs suspended, became in man a vertical supporting column, partially straightened by a new curve in the opposite direction, forming the "small of the back." Young babies are flat-backed at first, and only acquire this compensating curvature later when they develop into walking bipeds.

The centra, or bodies of the vertebrae, become flat-faced, thus stacking up into a firmer column than would have been possible with the original ball-and-socket centra, while the spinous processes of the vertebrae all come to slope backward and downward, instead of in the antielinal fashion, as in quadrupeds generally.

Furthermore, the axis and atlas of the cervical vertebrae become modified to permit easy rotation of the head, allowing the eyes of erect man to sweep the horizon, as no quadruped can easily do, at the same time permitting the eyes themselves to gaze straight out from the vertical face instead of looking downward along a projecting snout.

At the other end of the spinal column the tail bones, no longer useful in any of the former ways, telescoped together to form the coccyx. This fusion of the caudal vertebrae formed a mass which bent in and became embedded under the skin, forming a part of the floor of the pelvic basin, now a necessary underpinning for the support of the shifting visceral weight. So it came about that man in tucking his ancestral tail

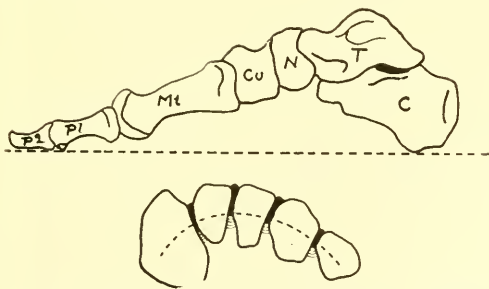


Skeleton of a hippopotamus, showing the anti-clinal arrangement of vertebral spines characteristic of quadrupeds, but not of bipeds. (After Hesse.)

between his legs turned this apologetic performance to advantage.

The thorax with its encircling ribs became flattened and widened as a consequence of upright posture, while the sternal bones, relieved from visceral weight, became firmly fused together and shortened, allowing more freedom and effectiveness of motion for the respiratory muscles.

The legs of man straightened, with a greater resultant efficiency in leverage, leaving the arms relatively shorter, since, with the passing of locomotion on all fours, legs and arms no longer needed to be of the same approximate length.



The two arches of the human foot. (From Walter, *The Human Skeleton*. By permission of The Macmillan Company, publishers.)

The human foot met its new responsibilities in a variety of adaptable ways. Being squarely plantigrade on the ground, the bones involved became arranged in two arches, one longitudinal and one transverse, to provide sprightliness to the gait, as well as an adequate

support to body-weight. One of the ankle bones, the *calcaneus*, projected out behind forming a heel, thus lessening the likelihood that the balancing biped might tend to tip over backward. In the hind foot of a quadruped such a development of a heel was unneces-

sary. The big toe, which in apes and babies diverges laterally from the second toe, straightened and lengthened in adult man into an efficient organ of support. In quadrupeds this responsibility is thrown mainly on the middle toe, which in such animals as horses becomes the only line of contact with the ground.

One of the farthest reaching results of uprightness was the emancipation of the arms from bearing the weight of the body in locomotion. This freedom allows the hands, with opposable thumbs, to be employed in exploratory touch, in defense, and in taking hold of things. The hinged wrist of man, with the rotating radius, increases the availability of the grasping hand, so that it can be used in a great variety of positions. Thus, instead of an organ specialized for a single purpose, like the hoof of a horse, or the wing of a bat, the hand remained fortunately a generalized structure capable of many uses. Bats are mammals that are able to fly, but at the price of losing their hands. Dr. Hooton, the anthropologist, in contrasting the foot and hand of man, happily describes the foot as a "specialist," and the hand as a "general practitioner."

The many adjustments resulting from erect posture are by no means confined to the skeleton. The pathologist, whose business it is to seek out the weak spots in the human frame and to discover the causes of human ills, has a great light shed upon his problems when he remembers that man is still in the making, and that his remote ancestors went about on all fours.

The Greatest Wonder in the World

The human brain is the greatest wonder in the world, for through it alone are all the other wonders made known. It is the brain that above all else is responsible for man's evident superiority over every other creature, since intelligence, rather than brute strength, is the greatest winning factor. Other parts of the bodily mechanism may gain more perfect elaboration in various animals than in man, but the human brain in its evolution has easily outstripped all other anatomical achievements.

The marvelous details of the rise of the nervous system with the brain are a story for the comparative anatomist to tell elsewhere. It would fill a very bulky volume, for the dawn of the mind, the most wonderful of all dawns, is also the most engaging episode in the whole evolutionary pageant. Moreover, only an animal with a human brain can realize anything about it.

Although no other brain, except that of the great elephants and the gigantic whales, is actually larger than the human brain, it is not the gross size and weight of man's brain that determines its pre-eminent dominance. Quality as well as quantity of brain must enter in as an important factor, as the relative size between the weight of brain and body shows. It will be seen from the accompanying table that the hummingbird has three times as much brain, compared to its body weight, as man, yet no one would say that it is as intelligent as man. It is obvious that there are brains and brains, with reference to quality as well as quantity.

TABLE OF RATIOS BETWEEN THE BRAIN AND
BODY WEIGHT

Tuna fish	1 : 37,000		
Ostrich	1 : 12,000		
Horse	1 : 500	Rat	1 : 28
Frog	1 : 170	Marmoset	1 : 22
Gorilla	1 : 120	Hummingbird	1 : 12
Lemur	1 : 40		
MAN	1 : 35		

The *cerebral cortex*, an interwoven tissue of nerve cells overlying the anterior part of the brain of the higher vertebrates, is of supreme importance as the center of intellectual life. An expert estimate

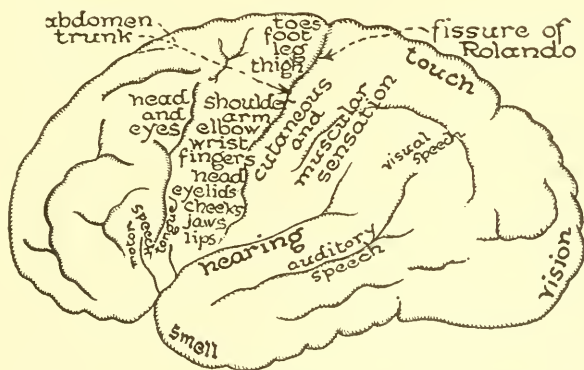


Diagram of the human cerebrum, showing the general distribution of sensory and motor centers.

has been made that the human cortex, which, if spread out flat instead of being wrinkled and folded, would occupy about a foot and a half square, contains over 9,000,000,000 nerve cells. These cells are so small that altogether they weigh a little more than a dozen

grams, and they could all be packed into a cubic inch of space. It is this restricted sheet of cortical cells that constitutes the marvelous headquarters of control for human behavior. In it are centers or patches of specialized nerve cells for the reception of impressions received through each of the various sense organs, such as eyes, ears, and touch endings, with neighboring areas devoted to the control of bodily movements. It will be seen from the map of brain localization, shown in the figure, that the receptive center for hearing is located in the temporal lobes of the cerebrum, that of touch in the parietal lobes, and that of sight in the occipital lobe, while the outgoing control of muscular movements is spread along the edge of the deep groove, the *fissure of Rolando*, marking the boundary between the frontal and the parietal regions.

The cortical centers of reception and disbursement are so hooked up and interrelated that together they form an intricate but unifying and efficient switchboard, reminding one of the central telephone exchange in a large city. This arrangement makes possible associations of various sorts, and furnishes a mechanism for the formation of ideas, as well as providing for the storage of garnered experiences, that have been embalmed in the preservative of memory and kept available for future reference.

In the course of vertebrate evolution the sense of smell was the first to acquire significant representation in the cortex, since it was the most useful of the senses in the case of lowly animals sniffing around with their noses close to the ground. As time went on, however, particularly in connection with arboreal life of the primates, cortical centers of sight, hearing, and muscular control gained a relative ascendancy, enabling natural selection to take a fresh lease on the task of sharpening the wits and elaborating the brain. The process is by no means completed yet, but even now it has gone so far that, in the case of man, a brain has been developed which enables him to perform such wonderful feats as weighing a star, or splitting off an electron from an atom, intellectual feats that are quite unthinkable in the case of any other animal.

Flint and Metal History

Man, with his handy hands, is the master mechanic, and the only animal that can use all sorts of tools. Monkeys and raccoons have grasping hands, but they are not very successful tool-users, for the reason that their brains have not caught up with their hands.

Animals whose brains outrun their hands would be equally handicapped, since they would have no adequate outlet for action. A fish equipped with a human brain would go crazy, with only fins to do with instead of hands.

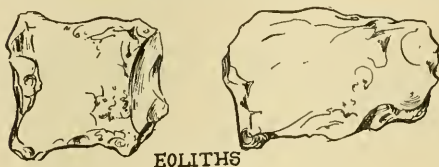
The use of tools and weapons is particularly important to man, because he is otherwise comparatively helpless, not having horns, fangs, hoofs, claws, or any such specialized anatomical instruments built into his body. He is also particularly fortunate in being able to shift, with his handy hand, from one tool to another, as animals, whose tools are a part of their bodily structure, cannot do. The origin of tool-using is of special interest to the anthropologist, because tool history can be traced back much farther than written history, or even the fossil record left by human bones. It, therefore, constitutes the very earliest evidence of man's presence on the earth.

The material out of which the earliest tools were fashioned was mostly flint, although other kinds of stone, as well as volcanic glass, or obsidian, were used. No doubt wood was used extensively too in various ways, but, due to its perishable nature, no witness of the fact remains. The first traces of human flint tools, according to Professor Bean, date back about 300,000 years. Their evolution can be traced through various stages of improvement down to historic times, when metals came to be employed largely in their stead. The successive cultural stages of tool-making are known as the Stone age, the Copper age, the Bronze age, and the Iron age. Today the subsequent Steel age, with its many instruments of precision, may be regarded as the high peak in this long evolution.

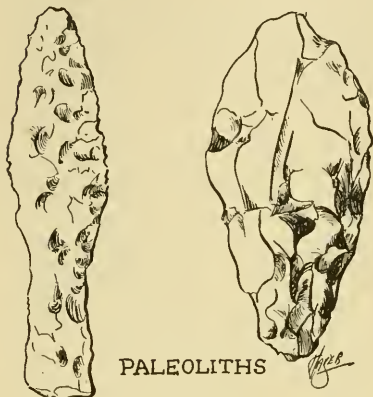
These successions did not occur simultaneously the world over, since advancement was much more rapid in certain parts of the globe than in others. For example, the rude primitive inhabitants of the British Isles were still back in the phases of flint culture at the time when the Greeks and Romans around the Mediterranean Sea had learned the use of bronze and iron. Furthermore, one kind of tool always overlapped and replaced another gradually, just as, in the matter of transportation, ox-carts, horses and carriages, bicycles, automobiles, and airplanes have succeeded each other without crowding out their predecessors all at once.

The Stone age has been divided into three divisions, *Eolithic*, *Paleolithic*, and *Neolithic*, according to the degree of perfection attained in fashioning stone tools or weapons.

Eolith implements are somewhat uncertain in character, although very stimulating to the imagination. They are "handy" stones, sometimes rudely chipped without any definite design, except that



EOLITHS



PALEOLITHS



NEOLITH

Flints, representing three periods of the Stone age. Drawn from specimens in the collection at Brown University. (From Walter, *Biology of the Vertebrates*. By permission of The Macmillan Company, publishers.)

they fit the hand and sometimes show evidence of having been used. Whether they ever did fit into a calloused prehistoric human hand is problematical. Doubtless the first tools and weapons were not made but were *found* and picked up, already sufficiently fashioned by such natural forces as frost and erosion. It was not until later that flints were made over by human agency into shapes for a definite purpose.

Paleoliths show unmistakable evidences of having been fashioned by man. The earliest ones are of very crude workmanship, perhaps roughly sharpened at one end, or chipped on one side only. Tools of more improved workmanship followed — stone axes, cleavers, scrapers, punches, spear and arrow heads, and flakes with notched sawlike margins or sharp knifelike edges. Some of these show a very remarkable degree of skill in their manufacture. The joy that

a modern boy experiences in the possession of his first jack-knife is a possible echo of the delight which our cave-dwelling ancestors felt when they succeeded in splitting off a knife-blade flake from a core of flint.

The paleolithic toolmakers worked for many thousands of years, as evidenced by the associated remains of extinct animals, before they

learned to *polish* their flint axes, chisels, and other tools and weapons, thus making the characteristic *neolithic* instruments. Meanwhile harpoons and needles of bone had been invented, and the beginnings of human vanity were recorded in the form of beads and other ornaments made of bone and shell.

"The change from the Stone age to the Age of Metals," says Professor MacCurdy, "was the most revolutionary step ever taken by man." Of the metals, copper was first employed in Egypt, mostly at first for ornaments, as early as 5000 B.C. This was followed by malleable bronze, and finally by iron, which is not at all easy to smelt out of the rocks where it occurs in nature. Iron, and particularly its modification in the form of steel, has come to be devoted to so many uses that if it were all magically withdrawn today, our civilization would collapse.

Getting the Upper Hand of Things

Something of man's later successes and failures in the control of his environment is related in the following pages on "Man, the Conqueror." In this connection, however, may properly be mentioned a few of the very first problematical steps that led to his ultimate triumph as a human being.

Primitive man was without doubt overwhelmed and molded by a dominating environment, and was to a very large extent the slave of his surroundings. He could not have been aware of very much in the make-up of what was about him, in the sense in which modern man knows his external world, any more than ants, running about busily in the grass, realize the clouds floating in the sky overhead. The revelations and mysteries of nature which the man of today senses on all sides, as well as the orderly sequences of cause and effect that make up events, probably made very little impression on our remote animal-like ancestors in the days when they were becoming human. They were probably unaware even of the existence of these surrounding factors, just as starfish are ignorant of stars, or ants are unaware of clouds.

Flashing lightning and crashing thunder primitive man did not understand, and it terrified him into superstitious subjection to the unknown forces about him. His dawning mind was enslaved because he did not yet know his world. Intellectual freedom, based upon a knowledge of the laws of nature, was to come only after long years

of endeavor, and was eventually to mark his most substantial triumph in emerging from his humble origin.

For thousands of years the best that he could contrive by way of a protection from devastating storms and climatic inclemency was to retreat to natural caves and rock shelters, where he disputed possession with cave-bears, cave-hyenas, and other formidable beasts. Whenever food was abundant he gorged himself. When it was scarce he starved. The artificial production of food, in order to secure a constant supply, he had not yet dreamed of, any more than did the wild animals about him.

Gradually "in man's ceaseless struggle to achieve his destiny," inventions beyond the possibilities of any animal with a lesser brain began to appear in the form of tools, weapons, weaving, pottery, the wheel, dugout canoes, and devices for shelter. There was at first probably little spare time in which to develop these higher arts and accessories of living, for, as in the case of wild animals, the day's work largely consisted in barely keeping alive. Moreover, whatever leisure was available could have been but imperfectly applied to the higher life, since the intellectual equipment necessary for this accomplishment was still wanting to a considerable extent. Even today modern man, already liberated more and more by machinery from continuous toil, is not always mentally equipped to dispose of his spare time with entire edification to himself and to others.

Another human accomplishment which no animal has ever attained centers around commerce or the acquisition and exchange of property. The great gap between mankind and even the most intelligent of animals is evident when it is realized how foreign to any animal behavior are even the most primitive forms of barter. Beginnings of hoarding, or the possession of property, are perhaps shown by honey-bees and nut-storing squirrels, but it is a long call from this instinctive behavior to the intelligent exercise of forethought that is practiced by economic man.

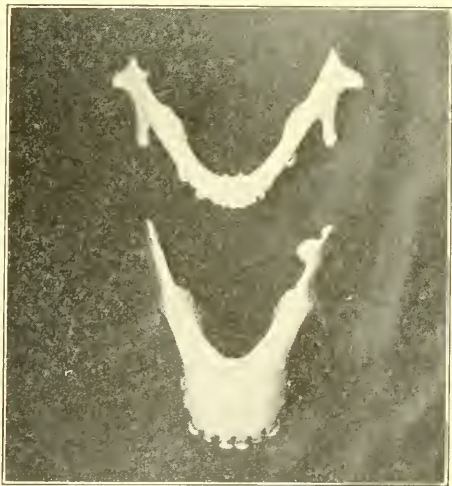
Thus, by means of agriculture, domestication, the use of fire, the development of fundamental inventions, the beginnings of economic practices, and above all by the gradual emancipation of the mind from the terrors of superstition and the misunderstandings of ignorance, did emergent man begin to get the upper hand of things, and to make the grand transition from the more or less animal-like solitary life of cave-dwelling to the co-operative social and intellectual life of modern man.

Gaining Ideas and Passing Them On

Once the brain of man had evolved far enough to incubate ideas, speech came to the rescue and made possible the transfer of ideas from one individual to another. Thus, the intellectual accumulations of experience and tradition were preserved and utilized, and the emancipating process of learning made possible. Language, it goes without saying, has been one of the most important factors in human evolution.

There are various ways in which animals can communicate with each other. Ants pass the time of day by touching antennae together, and dogs comply with the social conventions of the dog world largely through the sense of smell, but humankind has spoken and written language as the primary means of communication.

There are certain skeletal differences in the lower jaws of apes and humans which help to explain why one speaks and the other does not. In man the lower jaw spreads, like a letter V, while in the apes it is more U-shaped, due in part to the projecting canine teeth that make a "corner" between the incisors in front and the premolars and molars that are arranged behind along the side of the jaw. There is thus more room for the tongue within the arch of the human lower jaw than in that of the ape, which is of prime importance in speech. Moreover, the ape does not have a projecting chin to provide more room for play of the tongue, as in the case of man, although the whole face projects more. This is an important difference, for the two halves of the lower



Lower jaw of man (above) and ape (below).

jaw are anchored together by a bony formation on the inside, the so-called "simian shelf," a horizontal junction which reduces decidedly the available space for the tongue and its muscular attachment. In man, the simian shelf disappears with the outside de-

velopment of the projecting chin, and instead *genial tubercles*, small spines of bone projecting backward for the attachment of the genio-glossal muscles of speech, are present on the anterior inside angle of the lower jaw, just in front of the spot which in the apes is the location of the simian shelf. As Professor Hooton remarks, "The slang expression 'chinning,' meaning 'talking,' seems to have a certain evolutionary justification," but it is not enough, however, to possess the anatomical machinery for speech. A parrot has that. There must be cortical centers developed in the brain sufficient to make possible the realization of the significance of what is said in speech. Many animals are vocal and make a variety of sounds. It is said that chimpanzees have a vocabulary of at least a dozen words by which they express various emotions. Dogs can modify their barking to indicate different things, and crows modulate their "caws." No animal except man, however, puts together even a short sentence, and there can be no such thing as an animal grammar.

Skeletons in the Pleistocene Ice Chest

When did man become human? How long has it been since he emerged from among his nonhuman relatives to occupy a definite place on the evolutionary stage? Research and discovery in recent years have made it possible to give a tentative answer to these questions, which would not have been the case a century ago. There is no doubt as to the existence of contemporary human beings all about us, for they fall within personal observation. Tradition and historians are able to carry back the story of humanity, with diminishing certainty, through the Dark Ages at least to classical times. Beyond that period the uncertainty deepens, even when persistent archaeologists with their spades uncover buried cities, often built one above the other, and thus push back still further the outposts of human antiquity. The builders of these ancient cities fade from view, so far as archaeologists are able to inform us at present, about 5000 B.C., and when the thread is again picked up some 5000 years earlier, that is, about 10,000 B.C., it is the vanishing prehistoric traces of cave-dwellers which tell of the existence of man. Such troglodytic evidences of man are spread over a long indefinite interval of time, during which the ancestors of modern man probably endured a precarious existence, limited to life in small, struggling, isolated family groups. How to dwell together in anything like larger co-operative relationship had not yet been learned.

The critical emergence from long centuries of cave life, up through the beginnings of agriculture to community life, must have come during the transitional millenniums between 10,000 B.C., after the retreat of the last ice cap at the close of the Pleistocene period, and the earliest known traces of community or city life, around 5000 B.C. There were in the entire Pleistocene period, at least in the northern hemispheres, four great invasions of arctic climates, periods of perpetual winter with unmelted snow and ice, when an extensive glacial blanket covered the land the year around. Between these ice ages intervened warmer centuries without perpetual ice, when at times even tropical conditions obtained. It was probably within this span of Pleistocene time, in which there was such a wide range of alternating climates to keep adaptable organisms on the *qui vive* in order to maintain themselves, that man put in his initial appearance and gradually established himself among the existing forms of life. The Pleistocene period, therefore, is called the *Age of Man*, in distinction to the Cenozoic era, of which it is a part, and which is designated as the *Age of Mammals*.

There have been various attempts to estimate the relative duration of the three great geological eras, Paleozoic, Mesozoic, and Cenozoic, that are represented by sedimentary rocks from which fossil remains of animals and plants have been recovered. The following table, derived from various sources, shows the guesses made by a dozen investigators, in which the relative duration of the three fossiliferous eras is represented in percentages of the entire time that has elapsed from the beginning of the Paleozoic era down to the present.

TABLE OF PERCENTAGES OF TIME

	PALEOZOIC	MESOZOIC	CENOZOIC
Sollas	47.83	27.27	24.90
MacCurdy	66.00	22.00	12.00
Bean	63.63	25.45	10.92
Walcott	63.17	26.00	10.83
Wells	63.18	26.30	10.52
Boule	74.64	14.92	10.44
Osborn	60.00	30.00	10.00
Bretz	65.57	24.60	9.83
Schuchert	60.96	29.38	9.65
Lull	66.67	24.44	8.89
Buttel-Reepen	70.83	22.92	6.23
Barrell	77.89	18.63	3.48
Average	65.03	24.33	10.64

These estimates have been arrived at by various methods. That of Sollas, for instance, is based upon observed rates of erosion and sedimentation, although such rates are known to vary considerably with the conditions involved. Barrell's computations, on the other hand, depend upon the transformation of radio-active substances in the earth's crust. This latter method is probably the most reliable criterion for measuring the passage of time, for the reason that it has been experimentally demonstrated that the *rate* at which the transformation of radio-active substances occurs is constant. Thus, it serves as a reliable time-meter for determining the age of the rocks in which these substances are found. Uranium salts, for example, by discharging three helium atoms, become transformed into radium, which, in turn, undergoes still further progressive change, accompanied by the release of energy, by shooting off five more helium atoms when it finally becomes stable in the form of inert lead. Consequently, since this accurately timable transformation takes place at a definite rate, the time of the laying down of a stratum of rock in the earth's crust containing uranium-lead, or other radio-active elements in various stages of transformation, can be dated with considerable accuracy.

It will be seen from the table that an average of the opinions of the twelve experts cited indicates that the lapse of time during the Cenozoic era covered 10.64 per cent of the time since the first known plants and animals lived. Furthermore, the Cenozoic era is subdivided into periods of varying duration, of which the last, or Pleistocene period, meaning "most recent," is estimated to be approximately one sixth of the entire Cenozoic era, or, according to a most conservative guess, about 500,000 years. This is the spacious stretch of time in which we are to hunt for our earliest human ancestors. Since our primate cousins are known from their fossil remains to have existed as far back as the Oligocene period, there is no occasion to apologize for, or to feel in any way embarrassed by, the grotesque character of relatives so remote.

Aside from the indirect testimony of comparative anatomy and embryology, based upon the probable time needed to evolve so complex an organism as man, there are two lines of indisputable evidence of the great antiquity of mankind. The first deals with *artifacts*, or the tools and weapons considered in a previous section, which could only have been fashioned by human hands, and the second, with the occurrence of *human fossils*, the "poor Yoricks" that have frequently

been found associated with the remains of species of animals known to have been long extinct. These fragments of human skeletons, preserved in the vast Pleistocene ice chest which, as already pointed out, was restocked with ice at least four times, piece out for us something of the extensive pre-history of man.

The absorbing interest in human fossils is greatly enhanced by their scarcity. Not only destructive processes of decay but also the inevitable exposure of dead bodies to devouring animals were conditions to which primitive man was particularly liable.

The outstanding and much studied examples of Pleistocene man have nearly all been discovered since Darwin's day. They have, in the majority of cases, been recovered from the debris of limestone caverns, or found embedded in sedimentary deposits, along with the bones of extinct animals that serve to establish the time when they lived. For the most part they have been found in European countries, such as France, Spain, Belgium, Germany, and Austria, which have been more thoroughly explored by anthropologists than other countries, although a few notable specimens have come from such diverse regions as China, South Africa, Australia, and Java. Human fossils from North and South America are in no authentic instance, according to Dr. Hrdlicka of Washington, of the great antiquity characteristic of the famous representatives of early man from Europe and other parts of the Old World. As a matter of fact, it is not at all easy for any newly unearthed human fossil to run the gantlet of critical anthropologists, and to be admitted to good standing in the ancient and honorable society of genuine primitive man. It may be possible to fool some of these cautious investigators some of the time, but it is quite impossible to fool all of them in the end. To these experts we must turn for information in this field of study which lies beyond the opportunity and capacity of ordinary laymen to explore. Alluring as the ancient story is, there is a chance here to do no more than call a roll of a few of our most famous known fossil ancestors, and to refer those interested in the subject to the bibliography at the end of the chapter for further exploration and information.

Java Man

The oldest authentic fossil primate suspected of being human is *Pithecanthropus erectus* of Java, who lived either around the beginning of the Pleistocene period or at the end of the preceding Pliocene

period, some 500,000 years ago. Only the skull-cap, left femur, and three teeth of the fossil were found, far enough apart to suggest accidental burial, yet these fragments were sufficient to indicate the essentially primitive character of this famous individual. It has been briefly described as "more apelike than any man, and more human than any ape." With it were found the remains of twenty-seven different kinds of mammals, mostly of extinct types.

Heidelberg Jaw

Homo heidelbergensis is known only by a lower jaw, decidedly apelike in conformation, but supplied with teeth unmistakably human. This ancient being appeared on earth about 250,000 years ago, altogether too soon to matriculate at the venerable university, founded as recently as 1386 A.D., in Heidelberg, Germany, near which it was discovered in 1907. The fact that the jaw bone was buried under eighty-two feet of undisturbed sedimentary rocks, along with the bones of such extinct animals of early Pleistocene times as *Elephas antiquus* and *Rhinoceros etruscus*, indicates with considerable certainty when it lived.

Charles Darwin's Neighbor

In 1911 fragments of a human skeleton were found in England, different enough from all other humans to be classified not only in a separate zoological species, but even in a distinct genus from that of modern man. This individual, now named *Eoanthropus dawsoni*, had a human cranium but an apelike jaw, and was found in surroundings indicating a time of around 150,000 years ago. Piltdown in Sussex, where the bones were found, is only about thirty miles from Charles Darwin's home at Down, but Darwin died without any knowledge of his famous neighbor, in whom he would no doubt have been keenly interested had he been aware of his existence. Somewhat later parts of a second contemporary skeleton were found near the same locality.

The First Lady of China

Quite recently, in 1929, in the cave deposits of Chou Kou Tien thirty-seven miles southwest of Peking, were discovered the fossil remains of the "first lady of China," *Sinanthropus pekinensis* by name. The fact that she was securely embedded in limestone under

one hundred and ten feet of cave deposits, together with representatives of the early Pleistocene fauna, vouches for her very remote origin, although anthropologists are not yet completely agreed as to the probable time when she lived. This fossil is the first discovered evidence, accompanied with definite geological data, of the existence of early Pleistocene man north of the Himalayas.

The Neanderthalers

Coming down to times extending from approximately 100,000 B.C. to 30,000 B.C., there is ample and convincing fossil evidence of the existence of a peculiar race of cave-dwellers, principally scattered over what is now Europe, that were enough unlike modern man to be placed in a separate species by themselves. This is the species of *Homo neanderthalensis*, of which over a score of authentic specimens, more or less complete, have been found and critically described. They had brains and brawn enough to have lived somehow through the strenuous grisly days of the later ice ages, along with mammoths, woolly rhinoceroses, cave-bears, cave-hyenas, and other such ancient companions. The Neanderthalers made flint instruments and knew the use of fire. Sometimes they even buried their dead, and occasionally they disposed of them in cannibalistic feasts, as revealed by broken and charred bones. Those were the "good old days"!

Wild Horse Hunters

Following the Neanderthalers, and perhaps instrumental in their final disappearance, came two other races of mankind, the *Aurignacians* and the *Crômagnons*, who likewise dwelt in caves. No one yet knows whence they came, but there is plenty of evidence, fossil and otherwise, that they invaded Europe, eventually replacing the Neanderthalers then living there. No anatomical reason appears for placing these two races in different zoological species from that of modern man, namely, *Homo sapiens*. The Aurignacians were hunters of mammoths and wild horses, that in their day roamed over what is now Europe. Living some 30,000 years ago, they made enduring pictures of considerable artistic merit upon the walls of the caverns which they frequented, depicting principally the animals which they hunted. Many of these drawings, fortunately sheltered from the devastating tooth of time, are still preserved today.



American Museum of Natural History

Painted grotto drawings, reproduced from the original in the great rock shelter of Cuevas del Civil, near Albocácer, Castellón. A group of men, most of them armed.

Reindeer Hunters

The Crômagnons were likewise hunters, cave-dwellers, and artists. The animals they drew were largely reindeer rather than wild horses, showing that the climate where they lived had become cold in their day, because the reindeer inhabits only cold regions. Fossil remains show that the Crômagnons were physically a well-developed race, and it is generally believed that they were the immediate ancestors of modern man. They emerged from the last ice age, and can be traced down to about 10,000 B.C., when gradual emancipation from cave life and the beginnings of agriculture had their origin. Both Aurignacians and Crômagnons were expert flint workers.

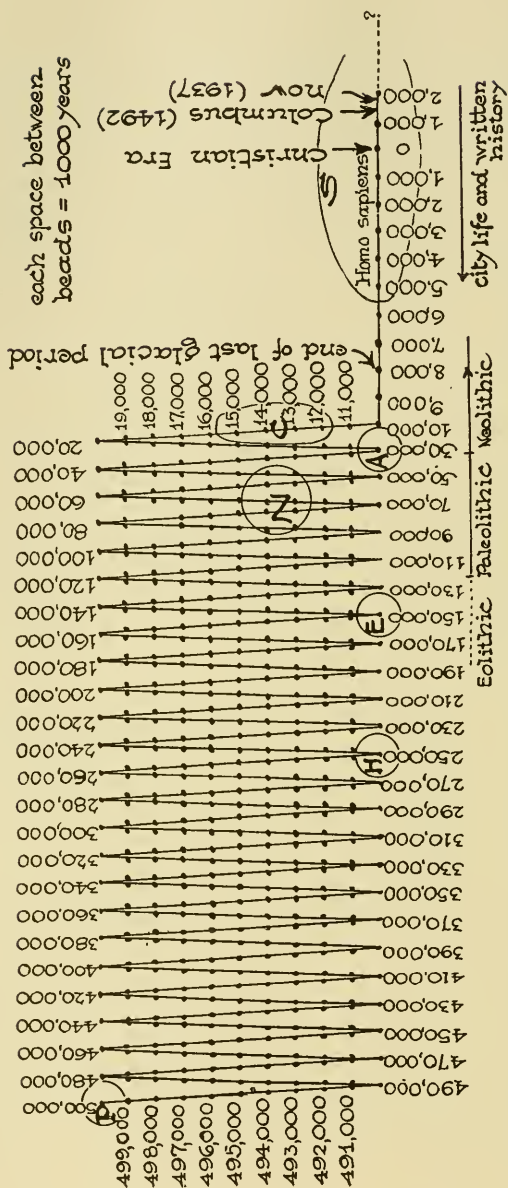
Human landmarks throughout the Pleistocene period are roughly indicated on the chart on page 560. The beaded line, in which each interval between the beads represents 1000 years, is drawn folded up like an accordion, in order to accommodate the diagram to a single page, with the last 10,000 years laid down horizontally at the right. To obtain a proper appreciation of the lapse of time in which man, although one of the most recent animals to occupy the earth, is involved, the entire beaded line, in imagination, should be pulled out straight.

Races

Anthropologists agree that, zoologically speaking, modern man constitutes a single species, called *Homo sapiens*, although it has been definitely established that, during the Pleistocene period, other species of human beings, now extinct, existed. It is obvious, however, that *Homo sapiens* today is made up not only of varying individuals, no two of which are alike, but of fairly well defined diverse groups of human beings, which correspond to what biologists designate among animals as different breeds. These groups in the case of mankind are called *races*.

The science of *Ethnology* is concerned with sorting out different races by means of an analysis of their several characteristics, besides tracing the origins of races, and mapping the migrations and dispersals from points of origin, through which man has come to occupy practically the entire earth.

There is considerable unavoidable confusion in defining just what is included in a particular race of human beings, because racial classifications may be based upon either geographical, linguistic, political, cultural, or religious standards, as well as upon biological criteria.



The origin of mankind in the Pleistocene period. P, *Pithecanthropus*; H, *Homo heidelbergensis*; E, *Eoanthropus*; N, *Neanderthals*; A, *Aurignacians*; C, *Cro-magnons*; S, *Homo sapiens*.

Furthermore, whatever the criteria that are employed, it is quite certain that in no case does there anywhere exist today a pure race of mankind, uncontaminated by any other race. The nearest approach to biological racial purity would be expected among inbred peoples, which have been isolated from diverse parental stocks for a long time, as, for example, the Eskimo tribes of the north, the hairy Ainu aborigines of northern Japan, the Igorots of the Philippines, the Veddahs of southern Ceylon, and the Pygmies of Africa.

Dr. Hrdlicka divides *Homo sapiens* into three primary races according to the pigmentation of the skin, namely, white, yellow-brown, and black. Skin color in itself is no measure of either inferiority or superiority. Its only biological significance is that it may possibly be regarded as an environmental adaptation to prevailing amounts of ultraviolet light in different regions of the earth. Even if a correlation between skin pigment and sunlight is demonstrated, the probable cause of it is more reasonably explained as an hereditary adaptation enabling the darker races to live successfully in tropical regions of greater intensity of sunlight, rather than that dark skin is the result of exposure to excessive sunlight, which has become hereditary. Unfortunately it is a superficial criterion that cannot be applied to our fossil Pleistocene ancestors of whose skin we have no knowledge. There is evidence, however, that these three great primary divisions of mankind were differentiated from each other before the time when the records of written history were begun.

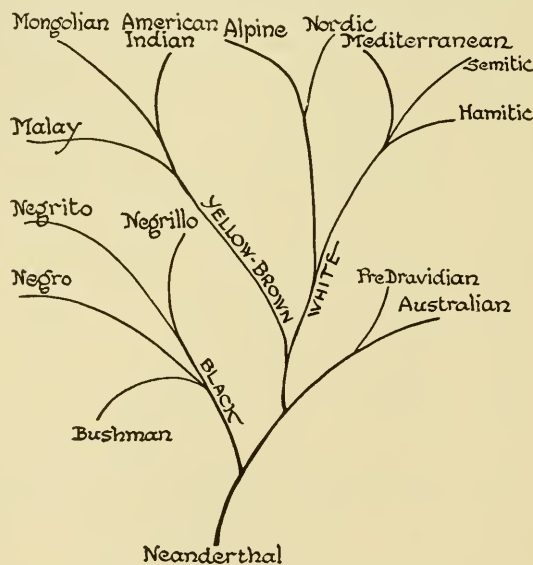
The *White race*, which may include individuals all the way from light blondes to dark brunettes, is frequently further divided into at least four sub-races, namely, the Mediterranean, Armenoid, Alpine, and Nordic. Individuals of the *Mediterranean sub-race* are typically short, slender, olive-skinned, narrow-nosed, and long-headed. They include various peoples of the Mediterranean coasts, Spaniards, Portuguese, Greeks, Cretans, some Italians, Persians, Berbers, Arabs, Phoenicians, most Egyptians, and some English. The *Armenoid sub-race*, characterized frequently by a prominent convex nose, have, in many instances, a decided flair for commerce, and an outstanding capacity for survival and advancement even under adversity. They include Armenians, Turks, Syrians, some Persians, and certain Jews. The *Alpine sub-race* is made up for the most part of stocky, round-headed people, including some Russians, Greeks, Swiss, North Italians, South Germans, Balkans, Czechs, Poles, and French. The members of the *Nordic sub-race* are charac-

teristically tall, fair-haired, and blue-eyed, with narrow faces and well-developed chins. They include Scandinavians, North Germans, Netherlanders, Flemings, many English, Scotch, and Russians.

The *Yellow-Brown race* is characterized usually by straight dark hair, high cheek bones, apparently slanting eyes, and broad heads. They include the various yellow Mongolians, American Indians, Eskimos, and Malays, also early inhabitants of the New World, such as the Aztecs of Mexico, the Mayas of Central America, and the vanished Incas of Peru.

Finally, the people of the *Black race*, with narrow heads, wide noses, thick nonapelike lips, include Negroes, Pygmies, Melaneseans, and Polynesians.

In the great centers of population, such as Europe and the Orient, as well as in the immigrant-filled land of the United States, hybridization of different strains of humanity has gone so far that it has become very difficult to draw racial lines of demarcation upon any satisfactory biological basis. Moreover, it makes considerable difference who does the classifying, for it seems to be almost impossible to eliminate the subjective factor of prejudice, when pride, patriotism, and personal bias are involved, as they are in racial matters.

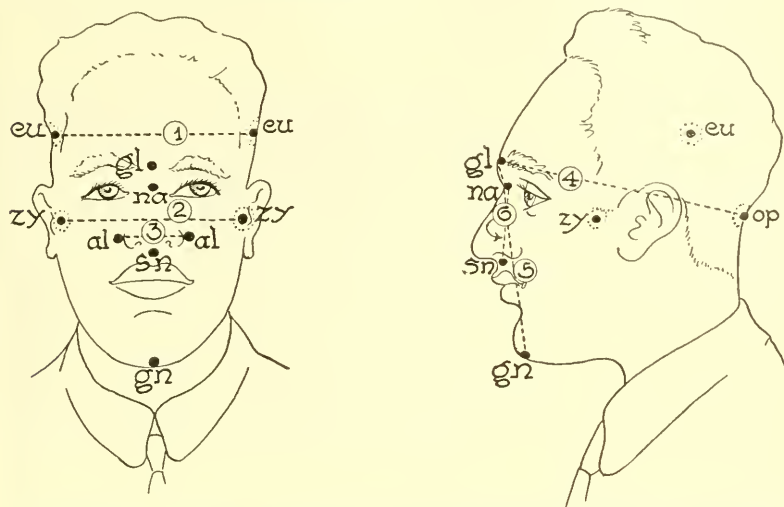


Derivation of races. (After Bean.)

The accompanying diagram indicates one expert's idea of the relation of the principal races and sub-races of mankind to each other.

Passing Muster

The analysis of physical differences, by means of which individuals can pass muster in order to be assigned to a particular race of mankind, is based upon certain generally accepted measurements. Lord Kelvin, the physicist, once wrote :



Landmarks for making anthropological measurements. *al*, alare; *eu*, euryon; *gl*, glabella; *gn*, gnathion; *na*, nasion; *op*, opisthocranium; *sn*, subnasale; *zy*, zygion. (After Sullivan.)

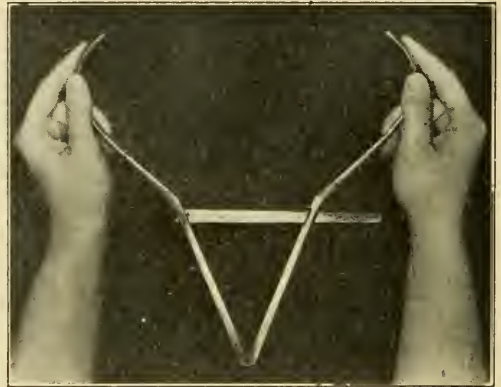
"I often say that when you can measure what you are speaking about, and express it in numbers, you know something about it, but when you cannot express it in numbers, your knowledge is of a meager and unsatisfactory kind; it may be the beginning of knowledge, but you have scarcely in your thoughts advanced to the stage of *science*, whatever the matter may be."

The science of measuring man is called *Anthropometry*. Dr. Louis R. Sullivan, formerly anthropologist at the American Museum of Natural History in New York City, has prepared a compact pocket manual, entitled *Essentials of Anthropometry*, designed particularly to aid travelers and students generally, who may be interested in the biological side of racial problems among the various peoples with whom they come in contact. In this excellent little manual Dr. Sullivan indicates *six essential dimensions* as a minimum, namely, head breadth, face breadth, nasal width, head length, face height, and nasal height, from which *four critical ratios*, or indices,

may be derived. They are cephalic, cephalic-facial, facial, and nasal indices. To these measurements he adds a list of *nine easy observations* which it is desirable to make in order to supplement the indices, and from this small array of fundamental data "we have a key to the relationship of racial groups in any part of the world."

In making the measurements for these indices it is necessary to locate eight landmarks on the head, which are shown in the diagram.

The measurements are not difficult to make, if one is supplied with calipers, such as are illustrated. The nine observations recommended are to determine skin color, hair color, hair form, eye color, the presence or absence of the *epicanthic* fold in the inner angle of the eye, thickness of the lips, character of incisor teeth, amount of beard naturally present, and the degree of hairiness of the



Spreading calipers as they are held while being used.

body. While many other measurements and observations are frequently made by scientists with particular ends in view, these six essential dimensions, and the ratios derived from them, together with the nine supplementary determinations by observation, are regarded as a minimum sufficient to furnish a definite racial picture.

The satisfaction of human curiosity in such matters as obtaining anthropological data was not always regarded as a commendable pursuit. Professor Hooton points out that an Act of Queen Elizabeth (1579-1598) declared all persons "fayning to have a knowledge of Phisiognomie or like Fantasticall Ymaginaccions" were liable "to be stripped naked from the middle upward and openly whipped untill his body be bloudye." Thus were the beginnings of scientific endeavor penalized in the days of Shakespeare and good Queen Bess!

The Biological Garden of Eden

Among the unsolved riddles that engage the anthropologist is the question of the actual time and place of human origin. One of the

outstanding differences between man and his animal relatives is his insatiable intellectual curiosity, that leads him to speculate even upon questions which he cannot always answer. Just when and where did mankind graduate from the long drawn-out school of animal life, and become qualified to be called human? Did man's emergence from his animal ancestry occur once only in a hypothetical Garden of Eden from which starting point he spread over the earth, as is inferred to be the manner of origin generally assumed in the case of different animal and plant species, or was the faint but important original line of demarcation between animals and man crossed repeatedly in various localities by different ancestral lines, which have contributed eventually to the compound make-up of what we call a human being? No direct answer can be made now to the question of human origin, nor in all probability can ever be made. What difference does it make, when and where man first came upon the stage? The important thing is that he has arrived and dominates life on the earth today.

Asia is regarded by many scientists as the probable original home of humanity. One of the reasons for this opinion is the fact that the vast continent of Asia is geographically adequate to have been the region from which man set out to overcome the world. It has a sufficiently large area and is now, or has been in the past, linked by land bridges with other important land areas on the earth, which would allow for human dispersal as we see it today. Moreover, there is geological evidence that it has been continental land since long before the Pleistocene Period, when the first known traces of man appeared. The earliest civilizations marked by historical remains, and the first known domestic animals also, are of Asiatic origin. That famous quartet of the oldest authentic human fossils, namely the Piltdowner of England, the Heidelberg Jaw of Germany, the Peking skeletons of China, and the Ape-man from Java are all far distant from the ancient central plateau of Asia. Dr. W. D. Matthews has pointed out that in evolution the most highly specialized and the most recent types of a series will be found distributed near their point of origin, while the more primitive and older representatives of a species, which have had more time to explore the world, will be found farthest away from the original starting point. This is "Matthews' Law," and it is borne out in the case of man, if Asia be regarded as the "Garden of Eden" in which mankind began his notable career. Naturally the spread of mankind, from whatever

point of origin, extended over a long period of time, and must not be pictured in terms of modern means of travel. There is very little reason to suspect that the great transition from nonman to man was in any way an abrupt event.

It may be appropriate to bring this chapter on Anthropology to a close with the following quotation from that genial old Roman dramatist, Terence: *Homo sum! humani nihil a me alienum puto.* (I am a man; and I think nothing appertaining to mankind is foreign to me.)

SUGGESTED READINGS

Andrews, R. C., *On the Trail of Ancient Man*, G. P. Putnam's Sons, 1926.

The barren wastes of the Gobi Desert, sand storms and blizzards, hostile tribes, chasing antelopes in automobiles, and toilsome digging for old bones alternate in these vivid pages.

Bean, R. B., *The Races of Man*, The University Society, 1932.

Differentiation and dispersal of mankind, treated clearly in a few readable pages.

Carrel, Alexis, *Man, the Unknown*, Harper & Bros., 1935.

A stimulating book by a Nobel prize man.

Gregory, W. K., *Our Face from Fish to Man*, G. P. Putnam's Sons, 1929.

An admirable illustrated account of human evolution as related by one of our foremost comparative anatomists.

Jones, F. W., *Arboreal Man*, Longmans, Green & Co., 1916.

The thesis of man's arboreal origin convincingly presented.

Haddon, A. C., *Races of Man and Their Distribution*, The Macmillan Co., 1925.

Standard presentation for the beginner. One of the best.

Hooton, E. A., *Up from the Ape*, The Macmillan Co., 1931.

Evolution of man from the primates. Although scholarly and rather exhaustive, it is alluringly readable because of welcome oases of humor.

MacCurdy, G. G., *The Coming of Man*, The University Society, 1932.

Prehistoric man, his remains and phases of his culture, and his relation to other primates, treated authoritatively with clearness and brevity.

MacCurdy, G. G., *Human Origins*, D. Appleton & Co., 1924.

A scientific study of man's culture in the Old and New Stone ages, and the ages of Bronze and Iron.

Osborn, H. F., *Men of the Old Stone Age*, Charles Scribner's Sons, 1919.

Authoritative, detailed, and fully illustrated.

Sullivan, L. R., *Essentials of Anthropometry*, Am. Mus. Nat. Hist., 1923.

Wilder, H. H., *The Pedigree of the Human Race*, Henry Holt & Co., 1926.

Yerkes, R. M., *Almost Human*, The Century Co., 1925.

A popular account of experiences with apes.

MAN AS A CONQUEROR

XXIV

MAN'S CONQUEST OF NATURE

PREVIEW. Has man conquered his environment? · The historical setting · Methods employed · Economic value of plants and animals: Uses of animals; indirect economic value of plants and animals · The other side of the picture · Harm done by plants · Harm done by animals · Methods of control · Suggested readings.

PREVIEW

If any one of us could have looked in on a group of our caveman ancestors with a view to comparing their control of the environment with that of the average man of today, there is no doubt of what we would say. Modern man has quite thoroughly conquered his environment and has control of its living as well as its nonliving factors. He has by means of his superior mental make-up gained control over his lower brute companions and molded their lives to his needs. He has conquered the forces of nature; harnessed water serves him with power; irrigation ditches make desert areas available for his crops and herds. He has analyzed soil so that he knows what crops grow best under given soil conditions; he has harnessed winds and made them pump water and hoist loads; he has learned how to use the sun's heat and how to protect himself from the numbing cold; he has controlled water and lighted his cities and his homes, and yet, is he a real conqueror? Are all of his efforts, directed as they are by science, ultimately successful? Is he truly the conqueror of his environment and the master of his future? Physically man has done much and done it well, yet he has made mistakes due to lack of complete knowledge, to misdirected enthusiasm, or to bias. Potentially man is a conqueror, but he cannot always overcome selfishness, egotism, and the lack of complete knowledge which is essential to an attack on any scientific problem. He cuts away forests to clear land which will produce his crops, at the same time bringing down floods and disaster; he builds dams to harness water power, while neglecting to provide the right kinds of waterways for fish that spawn in the upper reaches of those rivers; he overcomes one pest but introduces another in his

anxiety to obtain cheaper building materials. He makes mistakes and those mistakes cost him dearly.

Other factors enter into the picture. The biologist knows that the insects which inhabited this earth millions of years before man came on it have been, and still are, the most successful group of animals. They are adapted in many ways to escape enemies. They reproduce in great numbers and very frequently. They are omnivorous feeders, and numerically they outnumber all the other species of animals. Dr. Howard in a recent work¹ points out the fact that while man has jumped to the fore through his intelligence, this same intelligence may ultimately be his undoing, because he is giving to his insect competitors through his agricultural presents to them more and more food and thus opportunity for more rapid increase. These facts certainly should make us question man's supremacy, unless he can plan more wisely for the future.

There are many agencies working toward the goal of man's ultimate conquest of his natural environment. Most of these agencies are well directed, sane, and based on the best findings of science. But man, with his foibles, his illogical thinking, his greed and selfishness, introduces other factors. Particularly we have in this democracy of ours the leadership of the politician, the grafter, and mercenary private interests to contend with. To fight these obstructive forces we must know the facts and then go ahead as real scientists, prepared to use the facts wisely. The pages that follow should help clarify our thinking concerning some of the problems of economic biology and biological conservation.

Has Man Conquered His Environment?

A little over three hundred years ago our Pilgrim forefathers landed on the shores of Massachusetts Bay. They found wooded lands, rocky hills, with clear streams winding through shallow valleys filled with heavy undergrowth. The land was gradually cleared, farms were established, and settlements came into being. Today the countryside looks very different from the days when those colonists reached an inhospitable shore. And yet in the last fifty years, changes have been going on that are beginning to show how nature takes a part even when man has seemingly made a complete conquest of the land which he set out to conquer. In the last half century many New York and New England farms have been abandoned, the countryside between

¹ Howard, L. O., *The Insect Menace*, Century Company, 1934.

numerous towns and villages going back to its original state of woodland. Everywhere in nature we see this tendency to establish a balance and whenever man steps in to upset the balance that nature has established, sooner or later other living things tend to re-establish it.

In the case where man cuts the forests, clears the land, and does not grow crops this balance is lost. With trees and cover-plants destroyed, the soil is unprotected against storms of rain or wind and consequently water digs gullies and wind carries off the surface soil, to the ultimate wastage of the land. If man covers the cleared area with crops, a certain amount of protection is insured the land, but the original fauna and flora will probably never again be established. Our prairies were once covered with plants that have now disappeared as a living covering. They have been replaced by crops of domesticated grasses and grains, or by various "hitch hikers" from the ends of the earth — outcasts from man's estate — weeds. Indigenous animals to a great extent are gone also, often being replaced by the hangers-on of man's migrations, rats and mice, dogs and cats, and foreigners such as English sparrows and starlings. Man may *seem* to have conquered his environment, but when we note dust storms in the central west, hurricanes in the east, and frosts in our semitropical southlands, along with countless hordes of insect pests, we may with justice wonder if man really is in absolute control of the situation.

The Historical Setting

The history of man's domestication of plants and animals is a story which is only partly known. Just when this process began is conjecture. We do know that at a very early period primitive men living in the southern part of Europe, as well as an area in Asia and northern Africa, probably began the domestication of some of our common plants and animals. The how and why of man's control is also largely problematical. As nomadic life changed to a more settled form of residence it is easy to see that a food supply that did not have to be hunted was desirable. Doubtless women first discovered the values of wild grains and fruits, resulting in primitive methods of cultivation that led to the selection of seeds from better fruits for future plantings. We know that rice has been cultivated for over 5000 years and many of our common grains for an even longer period. The remains of Swiss lake dwellings which date back to about 10,000 B.C. show that oats, barley, millet, flax, and such fruits as the apple, pear, and grape were known and probably cultivated. In the Americas, corn was

cultivated in great terraced fields at the time of the Incas. When Jacques Cartier first viewed the site of the present city of Montreal, he saw there a village surrounded by cornfields. From earliest times the growing of grains and the progress of civilization have gone hand in hand.

Sheep, cattle, swine, and dogs appear to have been domesticated as far back as the Bronze Age. The dog was probably one of the first animals used by man, its domestication making possible that of other animals, especially sheep, goats, and cattle. The horse, which must have roamed wild in Europe during the Old Stone Age, was then used for food by the savage cavemen. Later horses were domesticated, but there are no authentic records of their use until about 2000 B.C., when they were used in Babylon, and three hundred years later, when they were introduced into Egypt. They reached their peak of usefulness in quite recent times.

Looking back on the history of agriculture we find that it is a story of very gradual crop improvement, both in yield and quality of product. Take, for example, the staple wheat. While the exact form of the parent wheats is not known, we do know that a wild wheat (an *emmer*) grows today without cultivation in the highlands of Syria and Palestine. As far back as 300 B.C. Theophrastus, the Greek "Father of Botany," reported several varieties of wheat. Different types of Indian corn, flint, sweet, soft, and popcorn, were known as early as 800 A.D. in the Mayan cities of Yucatan, while as many as 1000 varieties of rice are said to exist in India and China, where rice was probably first cultivated.

The early use of plants must have been merely to piece out the family food supply as hunting became poorer. Then as domestication of animals took place and man ceased a nomadic existence, grains were used as food for cattle and horses. At still later stages of his civilization man began to work for qualities, which were not thought of in earlier civilizations; more abundant or better fruits and grains, stronger beasts of burden, swifter horses, a better milk supply, and fleece that would supply better material for yarns.

Since man only, of all the animals, is able to make a record of what he has learned and to hand this knowledge down to the next generation, the results of this social inheritance are seen in the plant and animal production of today. First man, or more likely the woman who did the work, must have noticed that certain plants grew better and produced larger crops and more desirable fruits when given more

sunlight, water, cultivation, or fertilizer. Along with this came the seizing upon favorable variations and their continuance by cultivation. Lack of precise knowledge prevented certain success, and progress was slow. Crop production, moreover, has always been, and will continue to be, to a large degree dependent upon the vagaries of the weather, as the effects of the recent droughts in the United States prove. Nevertheless, as familiarity with different crop requirements increased, improvement in planting and care of the land has resulted.

Methods Employed

As far back as Roman times, agriculture was well advanced, for the Roman farmer plowed, fertilized, and irrigated his land. Later, under the feudal system of the Dark Ages agriculture declined for the reason that the peasants were uneducated and their lords interested in war rather than in the pursuits of peace. It was not until the coming of the eighteenth century that revolutionary changes began to take place in agricultural methods through the practice of crop rotation, and the growing of such crops as would provide food for stock during the winter season. Agriculture at the present time has become a science, and should be looked upon as a profession. Knowledge necessary to increased crop or stock production is disseminated through various channels, such as farm bureaus, the publications of the Department of Agriculture, various state agencies such as agricultural schools and colleges, the public school, and public press. The application of science to disease in both animals and plants has played an important part in promoting agriculture and animal husbandry, as is seen in the successful battle waged against many plant and animal parasites. The science of entomology aids the farmer by furnishing him with the knowledge of life histories of insects, of their methods of feeding, and of their natural enemies, indigenous or imported. Animals and plants introduced from the far corners of the earth have been made available with resulting benefit to the farmer.

It should be noted that relatively little advance in plant and animal improvement would have been possible had it not been for the application of certain scientific principles explained in other pages of this book. Although man had bred plants and animals for many thousands of years, it had been a very unscientific procedure, conducted by a "hit and miss" method. Long before the rediscovery of Mendel's laws in 1900, man had used selection to improve his stock and nature had helped by occasionally producing hybrids which could be propa-

gated asexually. Burbank's well-known adventure with the potato seed-ball was doubtless due to the fact that the flower which produced this seed-ball had been pollinated from another plant with different qualities from those of the Early Rose potato plant that produced the seed-ball. All that is known of this story is what has been told by Mr. Burbank, how he discovered the seed-ball, watched it develop, and the following year planted its seeds. He tells of the great variation in the offspring which grew from these seeds and of his selection for propagation of the tubers from one of the plants that gave rise to the famous Burbank potato, still one of the most popular products of the potato industry.

The case just cited illustrates one of the most common methods used by plant and animal breeders today. It has been recognized that two types of variations exist in nature. The first is that of so-called *fluctuating variations*, seen in all living things, which, for example, result in the bearing of a number of fruits or seeds of different sizes by a single plant, or leaves of slightly differing shape by a tree. Such variations, however, as the agriculturist knows are not handed down from one generation to the next. The second type of variations is called *mutations* or *discontinuous variations*. This knowledge has quite revolutionized the methods of plant and animal breeders, and they now attempt to find and propagate mutants, instead of trying to make use of variations that are not capable of being handed down to the next generation.

Methods used in selection have also changed. We use selection for plant and animal betterment, but we do not necessarily always select the best appearing fruits or largest seeds for future planting. As Donald F. Jones has well said, "Science now shows how a bumper crop of all good ears may be grown from nubbins, but they must be the right kind of nubbins."¹

Most important of the investigations in the research program of the Department of Agriculture is the search for a "superior germplasm." When such a superior stock becomes available, it is perfected and the results turned over to the practical breeder for perpetuation. The isolation of strains having superior breeding possibilities is of tremendous value to the farmer because it not only enables him to grow more plants in a given area, but also plants of better quality. In 1935, the parasitic organism, stem rust, cost the farmers in North Dakota alone \$100,000,000. Since over 100 strains of black stem rust

¹East, E. M., *Biology in Human Affairs*, McGraw-Hill, 1931.

have already been found, it is a very serious enemy of the wheat crop. Fortunately, in the epidemic of 1935 a new spring wheat, the Thatcher, developed by the Minnesota Agricultural Experiment Station in co-operation with the United States Department of Agriculture, proved resistant to all known strains of rust.

A recent exhibition in the Department of Agriculture displayed about 150 new superior varieties of field crops. No less than eight superior wheats, among them Turkey, Thatcher, Marquis, and Kanred, with several new varieties of oats and barley, are now cultivated on more than 40 million acres of crop land each year. New varieties of potatoes, such as the Katahdin, resist some of the serious diseases of potatoes. Peas and melons unaffected by parasitic wilt have been developed, while fruits of superior color, appearance, and keeping quality have been evolved.

In livestock, animals have been produced that show greater resistance to disease, larger body size, better growth, better performance, and greater fecundity. In breeding these animals, it has been found that, through a use of Mendel's laws, certain of these characteristics are shown to breed true, since they are alike in both parents. An outstanding successful strain of cattle, known as the Santa Gertrudis, has been recently developed in Texas. The Department of Agriculture is now experimenting with crosses of Brahman and Aberdeen-Angus breeds of cattle to establish certain desirable characteristics. A new strain of sheep known as the "Columbia type," which is particularly adapted to the rather rigorous regions of the Northwest, has been developed from the Rambouillet and Lincoln breeds of sheep. Crosses of poultry have been bred which produce as many as 300 eggs per hen per year, as against less than 100 eggs from the average hen. At some state experiment stations certain cows of superior breeds have been found to produce as much as 1000 pounds of butterfat per year, while the average cow produces little more than 200 pounds per year. These are only a few of the accomplishments brought about by practical breeding experiments in this country.

Economic Values of Plants and Animals

The results of this gradual domestication of plants and animals are seen today in the very great value of our agricultural products and farms. According to census reports the value of farm property in the United States, in spite of the long period of depression, is more than

that invested in the manufactures of this great producing country of ours. Diversified farming is becoming more and more general. Market-gardening forms the lucrative business of many thousands of people near our great cities, and in many of our southern states where raising cotton has given place to diversified farming. With improved methods of canning and preserving, over \$165,000,000 worth of fruits and vegetables are used annually in addition to fresh garden products sold in markets or consumed by the grower.

Orchard and other fruits play an important part in agriculture. The citrus crop of the world has greatly increased in recent years because of the dissemination of knowledge of its value in producing vitamins. Grapes are commercially valuable for wine and raisins, while figs, olives, and dates play important parts as staple foods in many parts of the world. Nuts of various kinds are valued sources of oils and proteins. Sugar comes from sugar cane, beets, and the maple, its manufacture ranking as an important industry in many parts of the world.

Tea leaves with coffee and cocoa beans form the basis of man's most important beverages. The annual tea production of the world is estimated at over 17,000,000,000 pounds, while coffee has a yearly production of over 3,000,000,000 pounds. Cocoa, with an annual production of close to 1,000,000,000 pounds, is used in candy-making as well as furnishing the basis for a variety of beverages.

Spices of various kinds, vegetable oils, and various drugs are all plant products of considerable economic importance.

Fiber plants rank high in our list of economically valuable crops. Cotton, in addition to its use in the home, has an important place in the manufacture of cellophane, guncotton, smokeless powder, and as the basis of celloidin lacquers and varnishes so necessary in the automobile industry. From its seeds a valuable oil is derived, while its refuse makes fodder for cattle. Other important fiber crops are flax, the bast fibers of which are made into linen, while hemp, abacá, sisal, and henequen are used for making twine and rope.

The values of forest products need only be mentioned. Wood is important in the construction of buildings, shipbuilding, airplane construction, furniture, and trim as well as in the rayon and paper industries. Scores of important chemicals are derived from wood. Man still uses a surprisingly large amount of wood for fuel, especially where forests are still existent. The latex of the Brazilian rubber tree

(*Hevea brasiliensis*) and other rubber-producing plants, various resins and gums, tannin, and cork are all important forest products.

Uses of Animals

It would seem unnecessary to list all of the animal series that man uses as food, but we cannot look at the census statistics without seeing the direct value in dollars and cents of our meat-producing mammals. Three billion dollars' worth of such animals is a pretty large investment, even in so rich a country as the United States. In addition, there are the various products which come from cattle, namely, milk, butter, cheese, and leather. A few wild mammals such as deer, bears, and, in the arctic regions, seals and walruses are also used for food. Birds both wild and domesticated, and their eggs, form part of our food supply, although wild game birds are disappearing so rapidly that we cannot consider them as a source of food except among the Eskimos of the arctic region. Amphibians, for example the large bullfrogs, furnish food for epicures, while some reptiles, such as the iguana and even snakes, are eaten in some parts of the world. There are edible salt-water turtles, too, many of large size, the leatherback and the green turtle often weighing six to seven hundred pounds each. The flesh of the diamond-back terrapin, an animal found in the salt marshes along our southeastern coast, is highly esteemed as food.

Fish is a food the world over. Among fresh-water species, white-fish, pike, and the various members of the trout family are valued food and, especially in the Great Lakes region, are so abundant as to warrant the establishment of important fisheries. By far the most important food fishes, however, are those which are taken in salt water.

Among invertebrates used for food the much desired lobster should not be omitted. Because of the esteem in which it is held, it has been almost exterminated in many localities. The canning of lobsters, crabs, and shrimp ranks as an important industry in many parts of the world. Molluscs, especially oysters, clams, and scallops, are much sought as delicacies, and form the basis for important industries, particularly along our eastern coast. Lower forms are little used as food although the Chinese are very fond of holothurians, which are preserved by drying and are called "trepang." In the West Indies the soft parts of sea-urchins are considered a delicacy. Finally, the honey-bee furnishes us with honey, of which over 60,000,000 pounds are used every year in this country.

Although the advance of civilization has been coupled with the domestication of animals, particularly as beasts of burden, many other values might be noted. The furs of many wild animals, especially the carnivores, such as seals, otters, sables, minks, and others, are of much economic importance. Among the domesticated animals, sheep, Angora and Cashmere goats, the camel, and alpaca are most used. Nor can we omit the larva of the moth, *Bombex mori*, which produces raw silk, the basis of an important industry in China, Japan, Italy, and France.

Many other economic values depend upon animals. In past ages protozoans, as well as diatoms, had an important part in rock-building and today their skeletons form the basis of some of our polishing powders. Nor must we forget their place in the formation of oil deposits, since the shells of diatoms and foraminifera in the deep borings are almost always indicative of the presence of oil. Corals have played a considerable part in the formation of islands and the red coral of the Mediterranean is valued for ornamental purposes. Pearls, the finest of which come from the north coast of the island of Ceylon, are formed by the secretion of mother-of-pearl by the mantle of the clam or oyster around some irritating substance, such as a grain of sand or a parasite. The pearl button industry in this country is largely dependent upon fresh-water mussels, shells of which are cut into buttons.

Whale oil, obtained from the "blubber" of several species of whales, and formerly used for illumination, has now become a commercial lubricating oil. Neat's-foot oil, derived from the hoofs of cattle, is another commercial lubricant. Tallow, from both cattle and sheep, and lard from hogs have many well-known uses. Cod-liver oil, a by-product of the codfish, is used for medical purposes. There is obtained, too, from the menhaden of the Atlantic coast, an oil used in dressing leather and making paints. Great quantities of menhaden go into the manufacture of fertilizers. Leather made from the skins of cattle, horses, sheep, goats, alligators, and snakes is put on the market in the form of shoes, pocketbooks, coats, gloves, and other articles. Horns and bones are utilized, for making glue as well as combs, buttons, and handles for brushes. Ivory is obtained from the tusks of the elephant, walrus, and other animals. The musk deer, musk ox, and muskrat furnish musk used in the preparation of certain perfumes. Ambergris, a basis for delicate perfumes, is formed in the intestines of the sperm whale.

Indirect Economic Value of Plants and Animals

The Biblical statement, "All flesh is grass," is literally true of the herbivorous animals, which eat not only grass but also untold masses of weeds that otherwise would crowd out useful plants. Just as plants furnish food for some animals, so do some animals for carnivorous species. Protozoa and many kinds of tiny plants form the food supply of forms higher in the scale, especially crustaceans and worms, which in turn are eaten by fishes. Many fishes live on plankton or on smaller fishes that feed on plankton. Thus we see the aquatic world is a great balanced aquarium. Man disturbs this ecological balance when he dumps untreated sewage and factory wastes into a stream near its source, as in the case of the Illinois River. The immediate result of this unsanitary custom was the destruction of fish life for a distance of about 100 miles. It has been estimated by Professor Forbes that the Illinois River, before it was polluted by the Chicago drainage canal, produced annually over 150,000,000 pounds of fish food. On the other hand, diluted sewage when emptied into a river is utilized by bacteria upon which microscopic animals feed, and these in turn furnish food for crustaceans and snails, later eaten by fishes.

We have already seen the great value of the hymenopterous and lepidopterous insects to the agriculturist. There is yet to be mentioned the indirect value of insects as food for useful animals. Dr. Forbes, for instance, has estimated that over 50 per cent of the food of many fresh-water fishes is made up of insects, mostly aquatic larvae. Nor should we forget the service rendered by parasitic insects, native and imported, in their war upon harmful insects. Ichneumon flies and ladybird beetles stand high in this category. Insects also eat enormous numbers of weeds, often acting as scavengers. Many beetles and some species like the lac insect, which furnishes the basis of shellac; gall insects, from the galls of which pyrogallie acid is made; and the cochineal insect, one of the plant scales, produce substances useful to man.

The toad is of great economic importance to man because of its diet. It is known to eat no less than eighty-three species of insects, mostly injurious. On the whole, our common snakes are beneficial to man. Even the rattlesnake and copperhead feed upon harmful rodents.

The food of birds makes them of great importance to agriculture. Investigations undertaken by the United States Department of

Agriculture (Division of Biological Survey) show that a surprisingly large number of birds once believed to harm crops really perform a service to farmers by killing injurious insects. Even the much maligned crow eats, as well as grain and fruit, mice and harmful insects, notably grasshoppers, and feeds its nestlings many more. A. H. Howell, in Bulletin 29 of the Biological Survey, lists 85 species of birds known to eat boll-weevils, based on stomach examinations of 3114 birds. The bluebird includes grasshoppers, ants, spiders, weevils, tent caterpillars, army-worms, cutworms, and the codling moth in its diet. Swifts and swallows eat flies, and cuckoos and blue jays eat hairy caterpillars, relished by few other birds, while much of the winter food of chickadees consists of eggs of aphids or plant lice. Ants are eaten by many species of birds. Larvae of beetles, mostly injurious, are preferred by crows, blackbirds, and robins. Many observations indicate that nesting birds eat a large amount of food in proportion to their size, and consequently destroy vast numbers of injurious insects. A young robin three weeks old has been observed to eat 70 cutworms in one day; a young tanager, 150 cutworms in a day besides other food; and a young phoebe just out of the nest, as many as 200 good-sized grasshoppers in a day.

In addition to eating insects, nearly 300 species of birds eat the seeds of weeds and other injurious plants. Our native sparrows, the mourning dove, bobwhite, rose-breasted grosbeak, horned lark, crow blackbird, and other birds feed largely upon the seeds of numerous common weeds. An examination of the stomachs of a number of these birds showed that they had consumed over one hundred kinds of weed seeds. Tree sparrows alone are estimated to eat 875 tons of weed seeds every winter in the state of Iowa.

Some birds, such as cormorants, pelicans, herons, ospreys, bitterns, kingfishers, gulls, and terns, are active fishers, and thus may destroy food fish and distribute parasites. But gulls, as well as the buzzards of the West and South and the vultures of India and semitropical countries, are of immense value as scavengers. Birds of prey (hawks and owls) eat living mammals, including many harmful rodents, such as gophers, field mice, and rats.

In addition to their commercial value, mammals are useful in many ways. Browsing cattle keep down weeds, along with their consumption of grass and other forage. A few mammals are insectivorous, notably bats and moles, both of which destroy injurious insects. Some carnivorous animals, such as skunks, weasels, raccoons, coyotes,

and foxes, destroy harmful rodents and may be considered of more use than harm to the farmer.

The Other Side of the Picture

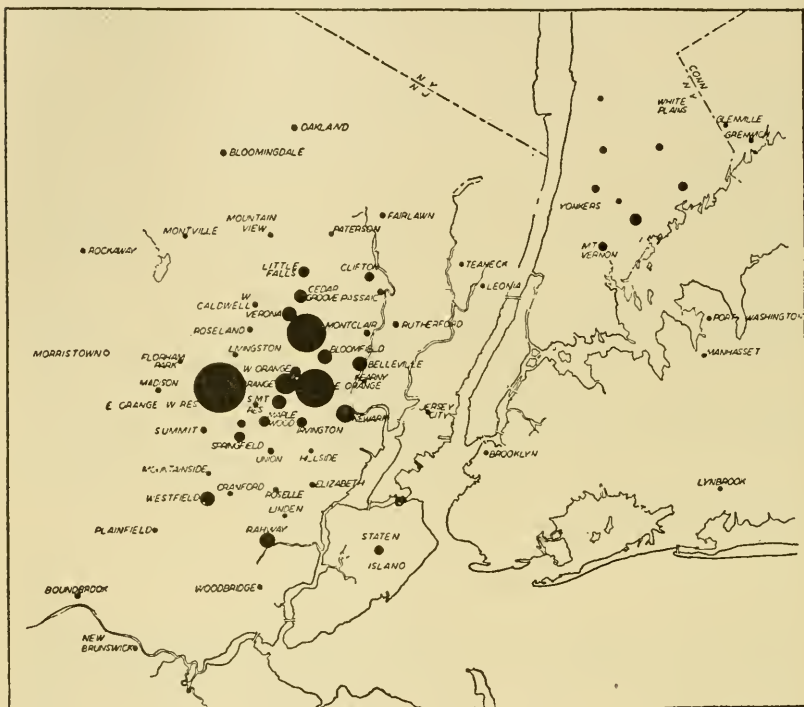
If we accept the statement that man is a rather doubtful conqueror of his environment and the living things within it, we should look at the other side of the picture and then attempt to strike a balance between the forces which aid and which hinder man in his quest for complete control over nature. Biological science must do more than catalogue lists of economic victories over nature, or of battles won or lost in the field of plant or animal husbandry. The facts noted in the preceding pages ought to give the student a basis on which to build an argument which will place man either on the defensive or in control of the forces of nature that surround him. The bare facts related here should be supplemented by much reading and investigation before a conclusion is reached. When the facts are weighed, one sees that man is by no means a complete conqueror, and that in some places he even seems to be playing a losing game. By noting some of the damage wrought by plant and animal enemies of man in the economic world, and then adding the plants and animals that attack him, directly causing disease and death, we will be in a better position to decide man's position as a potential conqueror.

Harm Done by Plants

In a general survey of harmful agents, bacteria and fungi stand out as the most destructive. Leaving out death and illness due to bacteria which cause human disease, there is still a formidable list of plant enemies which do much economic harm. Of the two billion dollars of damage done yearly to the crops of this country probably a third comes from bacteria and fungi. Bacterial infections cause such diseases as wilts, which attack cucumbers and melons; fire blight, due to a bacillus attacking fruit; bean blight; the black rot of cabbage; and the soft rots that destroy many vegetables in storage. The brown galls of fruit trees have been proven to be of bacterial origin, as well as the watermark disease of the English willows, a blow to the cricket players of England. Potato scab is caused by an organism (*Actinomyces scabies*) closely related to bacteria.

The algaelike fungi, or Phycomycetes, include water mold (*Saprolegnia*), the downy mildews, and the true molds. The plant disease

called "damping off," which attacks seedlings, white "rust," the brown rot of lemons, numerous downy mildews that attack grapes or garden vegetables, and the once dreaded "rot" of potatoes (*Phytophthora infestans*) are among this group. The Ascomycetes, one of the largest classes of fungi, produce spores in a spore case called



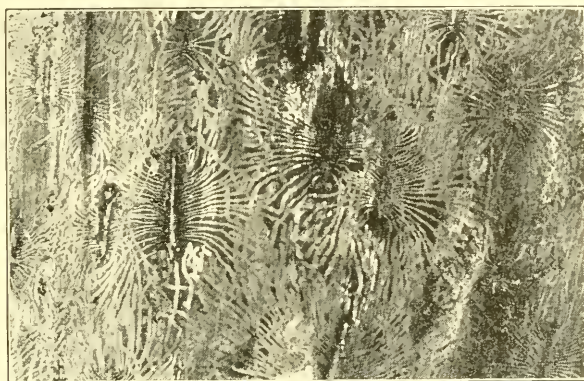
U. S. Dept. of Agric.

Map showing spread of Dutch elm disease from July, 1933, to February, 1934. The black circles show centers of infection.

an ascus. They include the powdery mildews so common on many garden plants, the black knot of plums and cherries, the brown rots of stone fruits, the black rot of tobacco, the wilts of cotton and watermelon, peach leaf curl, apple and pear scab, bitter rot of apples, the blue and green molds, and the yeasts, the latter of which are on the whole useful.

Shortly before 1910, an importation of Japanese chestnut trees to an estate near New York City introduced a blight which attacked our native chestnuts and spread so rapidly that today, in the eastern

part of the United States, they have almost been exterminated. Even more serious is the more recent introduction of the Dutch elm tree disease, a wilt that was introduced in an importation of European elm logs shortly before 1930. At that time, this disease had been found in several localities extending as far west as Indiana and Ohio and as far south as Norfolk, Virginia, marking places where the infected logs had been shipped. It attacks the wood and is spread by the European bark beetle as well as by other means. A determined campaign is now being waged to stamp out this disease, which, unless controlled, will doom our native elms to destruction as it has those of



U. S. D. A. Circular No. 323

Dutch elm disease. Brood galleries of *Scolytus multistriatus*, an imported beetle.

Europe in the past fifteen years. The latest estimate by Charles Lathrop Pack calls for the destruction of 25,000,000 trees in order to save the remaining elms on this continent. In view of a program of this magnitude it would seem impossible to save our elms, because of the difficulty in completely eliminating the fungus.

The most important class of the fungi from the economic viewpoint are the *Basidiomycetes*, fungi that bear asexual spores on a characteristic structure called a *basidium*. Among the worst pests of this kind are the corn smut, which causes the commonly seen smut balls in ears of corn, many different grain smuts, grain rusts, and one white pine blister rust, besides many fungus diseases of wood. In this class are also found the mushrooms, both edible and poisonous.

If we add to the above list the poisonous plants of this country, such as loco-weed, jimson weed, poison ivy, poison oak, and poison sumac, we have a formidable list of plants contending with man for supremacy.

One of the most serious factors against which man has to fight has recently been called to the attention of scientists by Professor E. C. Stackman of the University of Minnesota, and that is the rapid appearance of new strains of harmful fungi. A single reproductive cell of a grain smut was isolated and grown under laboratory conditions. In a relatively short time 112 distinct physiological strains were produced from the original plant. This means that under natural conditions there are new strains constantly arising, that will in time attack new crops as they are planted, some living on varieties of wheat, others on oats, barley, or rye. In other words, nature is constantly at work producing new varieties, either through mutation or through sexual crossing of existing varieties, thus forming hybrids which are different from the original parents and which have the possibilities of attacking different grains from those their parents live upon. It looks as if man was less than one jump ahead of such plant parasites.

Harm Done by Animals

It is not the purpose of these pages to do more than call attention to some of the animals harmful to man, but we should note that some of the most dreaded diseases, such as rabies, malaria, sleeping sickness, and amebic dysentery, are laid at the door of the protozoa. Among the echinoderms, starfish do much damage to shellfish and thousands are dredged up and destroyed each year by oystermen. Cestodes are parasitic in food animals such as cattle, swine, and fishes, and from these hosts may infect man. The class Trematoda also includes many parasitic flukes, some of which may infect man. The Nematelminthes include the hookworm (*Necator*) and *Trichina* as well as the *Filaria*, which sometimes causes elephantiasis. Parasitic worms also destroy annually large numbers of fishes, birds, and mammals used as food. Among the mollusca that do harm are the whelks which destroy other edible molluscs, and the shipworm (*Teredo*) that destroys submerged timber, such as the piles of wharfs and the hulls of vessels. Of crustaceans, crayfish may become a serious pest to cotton raisers by destroying young cotton plants. A few poisonous spiders exist, such as the notorious "black widow" and the tarantula. The ticks are of much importance because of their parasitic habits and the fact that they carry other parasites, such as the protozoan that causes Texas cattle-fever.

It is the insects, however, that must rank highest as man's com-

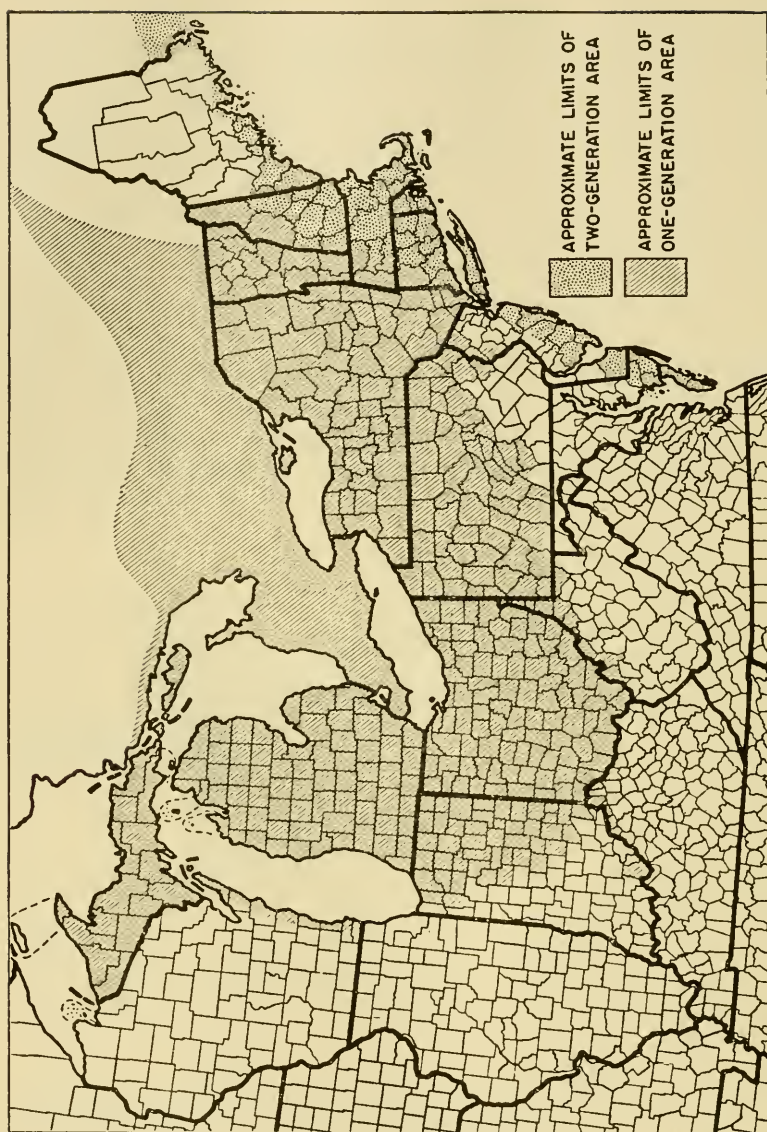
petitors. The most successful and most numerous of all animals, estimated to do from \$1,000,000,000 to \$2,000,000,000 annual damage to our crops as well as unestimated harm to man's health and comfort, they are indeed to be reckoned with. Insects are of especial importance to man because of their relation to his food supplies. Plagues of locusts have scourged many lands since earliest history, but with increased cultivation and the introduction of new crops, most insect pests have more recently turned from their original diet of weeds or grasses to feed upon the introduced food-plants. The chinch bug originally inhabiting the Great Plains regions and living on wild prairie grasses, with the coming of the settler and the raising of cereal crops changed its food supply and became a pest to the farmer. The potato "bug," a beetle that a few generations ago was an inconspicuous and not extremely numerous insect living on wild native plants of the family *Solanaceae* to which the potato belongs, upon the introduction of the potato to Colorado promptly changed from its original diet to the new food and spread to new areas where the potato was cultivated. Within a few years it had reached all parts of the United States and recently has appeared in England. These are only a few examples of many similar cases that illustrate the fact that man, in spite of all he can do, is spreading and aiding insect pests which are getting a large portion of his basic food supplies.

But native forms of insect pests are not enough. With the expansion of commerce and the intro-

duction of airplanes as well as railways and steamships, man is continually called upon to battle new importations of destructive insects, which in spite of strict quarantine laws are gaining a foothold on our



The present range of the Japanese beetle. An imported pest. What steps would you advocate to stop its rapid spread?



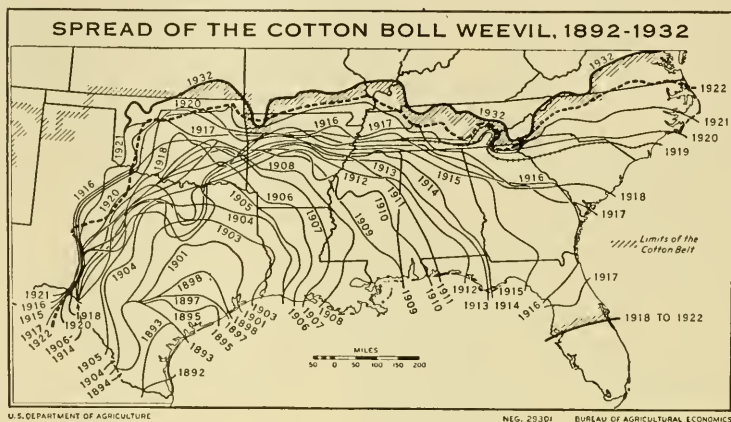
U. S. Dept. of Agric.

Map showing spread of the European corn borer up to the close of 1934. When two generations are produced during the year the larvae of the second generation winter in corn stalks or stems of other food plants. Suggest a method for combating the pest in this stage.

shores. During the war of the American Revolution, these stowaways began to arrive. Witness the Hessian fly cocoons brought in with straw imported from Germany to feed the horses of the Hessian troops. The progeny of these flies, by destroying wheat, have done more damage in this country than all the Hessians who fought during the war. One of the most recent importations and serious pests is the Japanese beetle. Introduced in the soil around the roots of iris plants imported from Japan, it was first observed in New Jersey in 1916. At the present writing it has spread over 300 miles from the point of its introduction and has become a very serious menace over several thousand square miles of territory. The Mediterranean fruit-fly, since its discovery in Spain in 1842, has spread to all parts of the world, gaining a foothold in Florida in April, 1929. Because this fly breeds in citrus and other fruits, as well as in peppers, tomatoes, lima beans, and eggplants, its introduction was a serious menace to the crops of this region. The situation called for strong action in which the state of Florida and the national government took immediate part. A quarantine was declared and no fruit shipped from the infected area. All trees, vines, or plants on which the flies fed were destroyed, and trees in nearby areas thoroughly sprayed at frequent intervals. This treatment was so effective that by November 16, 1930, no flies or infected fruits or vegetables being found, the quarantine was lifted. But we are not always as fortunate with imported pests. Take, for example, the European corn borer. Because of the nocturnal habit of the moth, which produces the caterpillar, it was not discovered in this country until it was too late to combat it effectually. Now, as the map published by the Department of Agriculture shows, it has spread widely over the entire northeastern part of the United States and is rapidly approaching the corn belt. The story of the incredibly rapid increase of some of these insect pests is repeated again and again. Our cereal crops are attacked at every stage of their existence. Weevils destroy the stored grain, cutworms attack the plants in their early stages, biting insects such as locusts destroy the leaves, and bugs suck the plant juices, while various boring insects such as the corn borer or the codling moth destroy the grain or fruit.

What is true of food plants is true also of the fiber crops and forests of our country. The cotton boll-weevil, imported from Mexico in 1892, has spread over the entire South, in some places entirely changing the economic life of the farmer, and causing replacement of the

cotton crops with other types of agricultural products. The cotton boll-weevil lays its eggs in the young flower bud, while the larvae feed on the substance within the bud, causing it to drop off, with the consequent non-production of cotton fiber. Beetles also lay their eggs in the young bolls of cotton, with the result that they become discolored, thus ruining the cotton produced. It is estimated that



over half of the cotton crop is destroyed by the boll-weevil. Because of protection offered by the cotton boll, the weevil is difficult to exterminate. Parasitic insects have been introduced to prey upon this pest; infected bolls and stalks are burned; crops are rotated and the ground plowed under for two or three years at a time in order to destroy the wintering weevil pupae. However, nothing has succeeded in stopping the boll-weevil's advance over the cotton-raising South. Today it is considered to be one of the greatest crop-destroying imported pests. The gypsy moth, the cabbage butterfly, the codling moth, and scores of others give rise to untold billions of caterpillars each year which strip our trees and shrubs of their leaves. Locusts move in swarms across the country, leaving a wake of devastation in their path. Plant lice and scale insects take their toll of fruit and forest trees, and beetles, too, such as the hickory borer, threaten the existence of all of the hickories in the eastern part of this country. The Englemann spruce beetle and the mountain pine bark beetle, which have already done enormous damage to the forests of the Far West, are rapidly spreading their areas of destruction. Insects from almost every order do harm to man, so why multiply the list.

Methods of Control

It might seem a hopeless fight that man is waging with his insect foes, especially as he is constantly introducing new species and just as constantly providing more food for them. It seems, indeed, like an endless chain of difficulty. Nevertheless, man has his brains and his social inheritance to aid in the fight. He has organized his forces through such agencies as the United States Department of Agriculture and its various bureaus, state agricultural agencies, public and private research laboratories, as well as control and quarantine offices in various parts of the country. A very large number of highly trained scientists are at work, both in this country and abroad, studying life histories, looking up plants fitted to withstand insect attacks, and running down parasitic enemies of harmful insects.

Methods of control have been worked out along several lines.

(1) Natural enemies of insects which do harm are found and encouraged. Many of these enemies are already "on the job." Insect-eating birds, toads, frogs, and snakes, as well as insect-feeding mammals, are examples. Many insects are attacked by parasitic fungi. To find enemies for imported crops it is often necessary for entomologists to go to the original country from which a given plant has come in order to study its insect enemies there, and to note how these are kept in check. The historic example of the discovery of a ladybird beetle as an enemy of the cottony-cushion scale, which threatened the orange industry of California, may be cited. In this case a natural enemy of the destructive scale was found in Australia, which, when imported to California, soon had the situation under control. Our latest enemy, the Japanese beetle, has possibility of control through an imported roundworm, while our native birds are also beginning to include it in their dietary. The importation of such insects as new species of ichneumon flies, that parasitize many harmful caterpillars, or of damsel flies or mantises, both of which feed on injurious insects, are examples of this kind of control. Scouts from the Bureau of Entomology in the Department of Agriculture are now at work in foreign countries seeking parasitic enemies of the European corn borer, the Mexican cotton boll-weevil, and our worst forest pests.

(2) A second method used in fighting insect pests is to study the life histories of both the pest and the crop which it attacks, and then either to change the crop in a given area to another on which the pest

will not feed, or else to plant a given crop earlier or later so it will mature a little ahead or behind the appearance of the insect enemy. Such, for example, is the early planting of cotton in the southern areas where the boll-weevil is a pest, or the late planting of spring wheat in order to escape damage from the Hessian fly.

(3) A third method of fighting insects comes through a study of their feeding habits. Beetles, caterpillars, and locusts bite holes in plants and chew their food, whereas bugs suck the juices of plants. In the case of the former, poisons are sprayed on the leaves which are eaten by the insect. Such poisons as lead arsenate or Paris green are used against the potato beetle and cabbage moths. In the case of the sucking insects, an oil spray or emulsion, that clogs up the spiracles and eventually kills them, is used. Mixtures containing nicotine, oil, soap, or kerosene are called contact poisons. In addition to these methods, picking off or shaking the insects into pans and then destroying them, drenching planted areas with creosote or other substances, or banding tree trunks with tar are employed.

The battle between man and his insect foes has only begun. Each year sees new developments in both agriculture and animal husbandry, and each year, with an increase of food plants and new strains of food animals, new species of plant and animal parasites as well as of pests are appearing, either introduced from other countries or developed in nature's own way from mutants or crosses. Will man ultimately win the battle? Who knows?

SUGGESTED READINGS

East, E. M., *Biology in Human Affairs*, McGraw-Hill Book Co., 1931.

An interesting and authentic survey of biological knowledge as it is applied for the benefit of mankind. Written by a dozen leading specialists in the fields of genetics, medicine, foods, public health, and psychology.

Gager, C. S., *General Botany*, P. Blakiston's Son & Co., 1926.

A general botany with much economic material included. Valuable for reference.

Henderson, J., *The Practical Value of Birds*, The Macmillan Co., 1927.

Useful for reference.

Howard, L. O., *The Insect Menace*, Century Co., 1934.

The title suggests the contents. An interesting discussion of a timely subject by an eminent authority.

Metcalf, C. L., and Flint, W. P., *Insects, Man's Chief Competitors*, Williams and Wilkins, 1932.

The title explains the point of view.

CONSERVATION AND ITS MEANING

PREVIEW. The usefulness of forests · Forest waste and methods of conservation · Waste and conservation of animal life: Fisheries; shellfish; birds; Mammals · Conservation of wild life · Present methods of conservation · Organizations for conservation: State conservation departments; Biological surveys; Federal agencies; Bureau of Fisheries; National Parks · Is there a unified program? · Suggested readings.

PREVIEW

This country has been blessed beyond many areas of the earth in its abundance of Nature's resources. The first settlers found forests, inhabited with game, covering the land, streams and rivers alive with fish, and great plains supporting herds of buffalo. Yet today, with our country embarking on almost its one hundred and fiftieth year of national life, its wild life is almost exterminated, its forests are only one eighth of their former size, and its oil, coal, and mineral deposits are rapidly approaching depletion. Increasing population has meant the use of more power, more fuel, more mineral wealth. Consequently man has disturbed more and more the balance of nature, sometimes with disastrous results. No one who has traveled through a cut-over or burned-over forest area, or through an exhausted coal or oil region, can escape seeing the necessity for immediate and drastic control of our waste. No fisherman or hunter who remembers the bounty of the streams and forests of former days can escape understanding why there are now restrictions on the size of the bag of game or limit of fish. All thinking citizens must realize not only the need for conservation of what is left of our natural resources, but also the necessity of intelligently adding to our supplies of living things by means of reforestation, fish culture, stocking of streams and lakes, as well as providing more food supplies and refuges for wild life.

The Usefulness of Forests

Forests have indirect values and uses other than commercial which mean more to man's future welfare than a supply of lumber or fuel or forest products, important as these are. History shows that as man has cut down forests, tilled land, and built cities, destructive physical

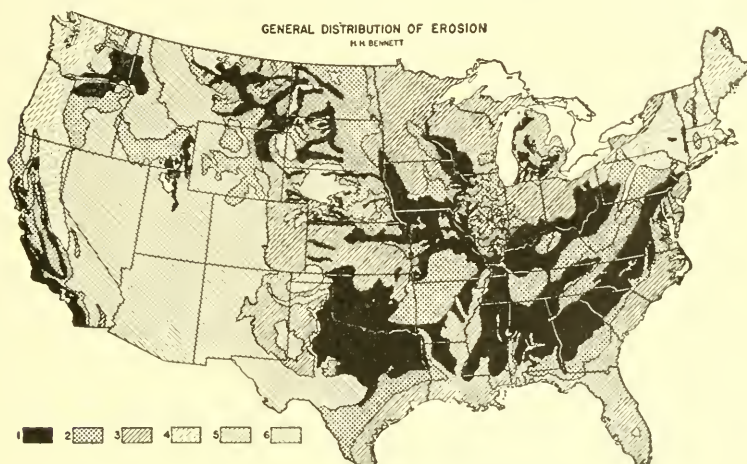
changes have resulted. When the earth's surface is covered with trees, their roots make a soil-mat which holds water in the ground, preventing a rapid run-off. The blanket of foliage above intercepts the moisture and allows a more gradual passage of water into the ground, while the soil under the trees, rich with an accumulation of humus and dead leaves, holds the water, so that a forest floor is estimated to absorb and hold back for some time a rainfall of four to five inches. But let the forest cover be destroyed by fire or poor lumbering, and what is the result? As soon as the forest cover is gone, the first heavy rain washes off the soil, carrying it to places where it will be of little value. The water lost by surface run-off in level areas like the Great Plains region varies from 15 per cent after light showers to 50 per cent during heavy storms. In sloping areas the run-off naturally is much greater. It is estimated that the annual wastage of soil in the country from erosion amounts to 1,500,000,000 tons, containing over 126,000,000,000 pounds of soluble mineral material necessary for the life of plants. In dollars and cents this wastage is estimated at \$2,000,000,000 annually. Most of this loss comes through man's carelessness with fire or downright rapacity in denuding forests through cutting without proper provisions for replanting.

The relation of forest fires to erosion and floods is seen in the following table, which was made after the devastating flood near Los Angeles, California, during the storm of December 30, 1933, to January 1, 1934. This area had been burned over a few months previously, with the result that the cover of chaparral and small trees was completely destroyed.

WATERSHED	RAINFALL, INCHES	PER CENT OF AREA BURNED	PER CENT OF AREA UNBURNED	RUN-OFF MAXIMUM, CUBIC FEET PER SECOND	EROSION, CUBIC YARDS PER SQUARE MILE
Verdugo . .	19.13	67	33	1000	50,000
San Dimas . .	16.85	0	100	51	56
Haines . .	11.26	68	32	1000	67,000

A study by C. A. Connaughton, of the United States Forest Service, on 3000 test plots of burned-over forest areas, comprising both cut-over areas and virgin timber, showed in general that the degree of subsequent erosion varied with the severity of the fires. Plots of virgin timber burned over showed only about half as much erosion as cut-over land having the same degree of forest fire.

It has been estimated that the transporting power of water varies as the sixth power of its velocity. This means the carrying power of water is increased sixty-four times if its rate of flow is doubled. From such figures it is easy to account for the enormous destruction by streams at a time of flood, as was witnessed in March, 1936, in the eastern part of the United States. The annual damage by "spring freshets" in cut-over areas in the East, the recent floods in the Ohio and Mississippi valleys, where the forest cover has given place to farms and cities, and the damage done by cloudbursts in denuded areas in the Southwest, all testify to the power of uncontrolled water and show the need of forest cover to hold back flood waters.



Erosion areas in the United States.

1. Area of most serious erosion; 2. harmful erosion widespread; 3. flat areas, slight erosion; 4. erosion generally not serious; 5. much serious wind erosion; 6. much erosion from over-grazing.

But erosion does damage in a more insidious way than through spectacular floods. A plowed area on a hillside allows more rain to run off than a similarly located area covered with grass. A plowed field allows more soil to be carried off by wind than does a similar field covered with grass. A plowed field will be left covered with mud after a heavy rain and the pores of soil will be found to be clogged with soft mud, making plant growth practically impossible. A glance at the map shows the very large area in this country in which more or less serious erosion takes place. A check-up with the map showing forest areas on page 605 makes clear that the areas of

least erosion are those which are still covered with forests, while those that show the greatest destruction by erosion are the areas where the cover has been destroyed without adequate replacement. The farms in the mountains of Tennessee, Kentucky, and on the eastern slope of the Southern Appalachians suffer most from water erosion, while great regions in the Middle West have been made subject to wind erosion through the removal of large areas of protective cover, thus giving the name of "dustbowl" to this region. This does not mean that farmers should not plow land and plant crops, but it does mean a lack of intelligent farm planning on the part of many farmers. Leaving a few trees here, or planting others there to form a windbreak, the use of grasses or grains in wind-exposed tracts, cutting up large fields into smaller ones in which diversified crops may be grown, planting grass along banks, and placing check dams in gullies already eroded are some of the ways in which farm erosion may be prevented.

Forest Waste and Methods of Conservation

When the white man first settled our eastern coast three hundred years ago, there was eight times as much virgin forest as there is today. The present total forest of the United States is less than 494,000,000 acres. More than 80,000,000 acres of this area have been burned or



The tragedy of forest fires.

Haworth

cut, so that they are now waste land. It is estimated that fire, worms, and insects destroy each year in the United States about 7,000,000,000 board-feet of standing timber. Add to this a timber production from 10,000,000,000 to over 44,000,000,000 board-feet a year, depending on the building demand, and we can see the wastage that is taking place in our American forests. It is estimated that we are deforesting at the rate of about 10,000,000 acres a

year. Forest fires caused by man's carelessness as well as by lightning have laid waste over 12,000,000 acres of forest land in a single year. A forest fire does much more than burn trees, for a severe fire usually destroys the organic material of the forest floor known as duff, thus preventing the growth of new forests for years to come, and in addition, it drives out or kills much wild life.

Other enemies to forests are parasitic fungi that destroy trees, and various insects which eat their leaves and tender shoots or bore into the wood. The caterpillars of the gypsy and brown-tail moths are chief agents of destruction in the first category, while various beetles may be listed in the second group. The Engelmann spruce beetle has destroyed millions of feet of timber in the Rocky Mountain region, while the Black Hills beetle has done similar damage in South Dakota. Much damage, too, is done by grazing animals, especially sheep. The recent Taylor Act, which throws the entire 165,000,000 acres of the Public Domain open to cattle and grazing interests, is a serious menace to our forests and wild life. In addition to all of this kind of wastage, if we add that caused through waste in lumbering, at the mills, through nonutilization of by-products, and especially in pulpwood cutting for the paper industry, where millions of small trees are sacrificed, we can see many reasons for a general and more scientific conservation of our forest resources.

Fortunately this country is beginning to awaken to the need of forest conservation and has numerous agencies both Federal and commercial at work toward this end. Many lumber companies are replanting cut-over areas and selecting with greater care the trees to be lumbered. Forests are being treated as crops to be harvested when ripe. Waste products are being utilized to a greater extent. All sawdust formerly had to be burned, but now alcohol, beaver-board, and other by-products are obtained from this source. Although much bark is used for tanning, still there is wastage here. More and more lumber is being treated each year with creosote or other chemicals as a protection against insects, thus effecting another saving. It is estimated that the treating of railway ties with creosote has resulted in an annual saving of around 1,500,000,000 board-feet. Much wood was formerly utilized in the making of boxes, for which substitutes are used. The Forest Products Laboratory of the United States Forest Service works upon the various chemical products obtained from wood and has shown a list of uses given on page 594, many of which are still not utilized. The trim of homes has been re-

CHEMICAL PRODUCTS FROM WOOD ¹

baking powder	lignin (at present one	printing ink
cellophane	fourth of wood is waste)	rayon
cellulose	pyroligneous acid	resin
cellulose acetate	oleo resin	sausage casings
cellulose nitrate	oxalic acid	sealing wax
collodion-film	paint	smokeless powder
ethyl alcohol	paper	soap
furfural	paper size	sugars
galactin	patent leather	synthetic camphor
hydrolyzed sawdust	plastics	turpentine
lacquer	polish	varnish

placed by metal or other substances, and in general the rate of forest cutting has been somewhat reduced by these and other means. Railroads are planting areas for the production of ties and each year sees more emphasis placed on the care and protection of forested areas. Recent figures indicate that over a five-year period, although the number of forest fires in national forests increased from 7601 for a previous five-year period to 9512, yet the number of acres burned over was less than half that burned in the previous period. Forest Service officials give credit to the members of the C.C.C. for this saving. Not only



Wright Pierce

Flood control work by the Civilian Conservation Corps. By means of wire mesh and small stones this mountain torrent is kept within bounds at a time of flood.

¹ U. S. Forest Service, Forest Products Lab., Madison, Wis.

have they built roads, cleaned up fallen timber and "slash," and cut fire breaks, but they also were on the ground early enough to prevent many of the fires from spreading.

The government agency which has to do with the carrying out of our forest policy is the United States Forest Service, a branch of the United States Department of Agriculture. Forest rangers keep in the field, continually patrolling forest areas. Fire towers are built from which observations are made, airplanes scout during the season of fire hazard in order to locate outbreaks of fire, and trained foresters are constantly at work repairing injured trees, cleaning up areas that are fire hazards, and replanting burned or waste areas with seedling trees.

Waste and Conservation of Animal Life

Fisheries

Fish have been an important food supply since earliest times, but we find that the drain caused by overfishing, commercially as well as in sport, is making severe inroads on the original fish population. Every sportsman well knows that with the coming of the automobile his former haunts have been pre-empted by others and that the supply of game fish has rapidly decreased. To an even greater extent overfishing has occurred in the oceans, due to the demands of increased population.

It is well known that fishes change their habitat at different times in the year, a fact which is made use of by sport and commercial fishermen. Although temperature changes and the quest for food play an important part in the migration of some fish, it should be noted that this habit in fishes as in birds seems to be due to the growth of the gonads and the ripening of eggs and sperms. In the ocean, migrations in a general way follow the coast lines. The continental shelf which exists along the eastern coast of the United States, giving rise to the Grand Banks off the coast of Newfoundland, marks the northern limit of the range of immense numbers of food fishes, particularly the cod. Consequently this area of the ocean has been fished to a very considerable degree, being the principal source of pollack, haddock, and cod.

The relation of the spawning habits of fish to commercial fisheries is important. Many of the most desirable food fish, such as salmon, shad, sturgeon, and smelt, swim in from the ocean up rivers in order

to deposit their eggs in fresh water. The Chinook salmon of the Pacific coast, which is the species most used in the salmon-packing industry, travels up the Columbia River over a thousand miles in order to deposit its eggs near the headwaters. Several runs of salmon occur at different points along the western coast, different species of salmon entering different rivers to deposit their eggs. The run of the sockeye or blueback salmon (*Oncorhynchus nerka*) on the Columbia



The romance of the Alaska salmon. After the eggs are laid in the headwaters of the rivers frequented by the various species of salmon, the old fish die. The young, after several months to a year, make their way to the sea, where all traces of them are lost. But when adult, these same fish apparently make their way back to the streams where they were hatched, to complete their life cycle.

begins in March or April and ends in July or August near the headwaters of the Salmon River in Idaho. The same species begins to run in the Fraser a little later, reaching its spawning ground in August and September, while in Alaska the sockeye has a relatively short run. The Chinook (*Oncorhynchus tshawytscha*) begins to run on the Columbia in February or March, and spawns as late as November or December in the high headwaters of the Columbia. Wherever the spawning beds may be, it has been found that egg-laying does not take place until the water has fallen to about 54° F. The relation of

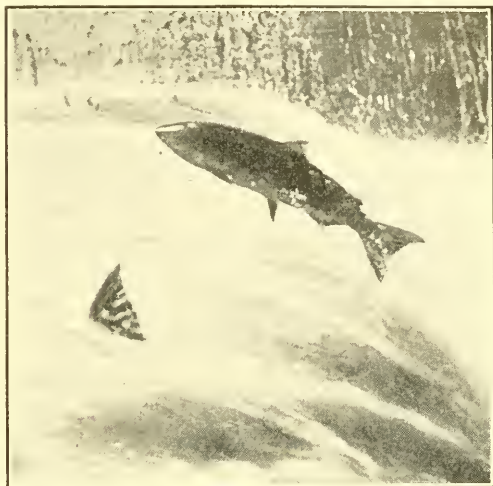
uncontrolled fishing to spawning is an instance of the need of wise legislation. Salmon and other food fish of similar habits, such as the sturgeon, are in much danger of extermination because of this relationship.

A further danger to fish is the pollution of streams. Thus the salmon have not only been depleted by overfishing and wasteful methods of fishing, but have been "discouraged" from ascending such streams as the Connecticut River by the great quantities of pollution present. It is reported that the salmon formerly ran up this river in such quantities that the farmers used to back their wagons to the edge of the stream and take them out by the wagon load for food and fertilizer. A somewhat similar story may be told of Lake Champlain. At the time of the Revolution, salmon used to run up from the St. Lawrence River into the lake and would then spawn in its tributary streams. Early maps of this region published in 1776 and 1779 indicate the location of "salmon fisheries" and records from the diary of the settlers run as follows:

"Sunday, Aug. 26, 1789. The water raised and Salmon run plentifully for the first.

Monday, Oct. 8, 1789. 365 Salmon taken."

The salmon industry in this region declined so in the next half century that we find "only straggling individuals are met with in Lake Champlain."¹ Nothing remains but the memory — or controversy — over when, and by whom, the last salmon was seen or caught in the lake.



Eastman Kodak

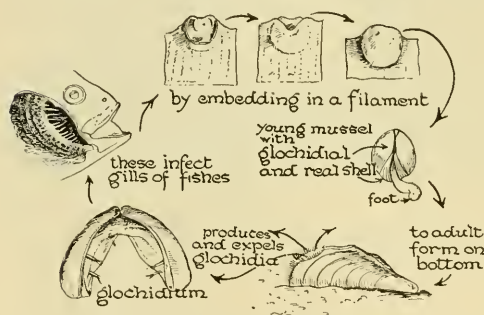
Salmon leaping falls. Proper fishways should be constructed where dams interfere with fish migration.

¹ From Thompson's *Vermont*. Published 1842. Quoted in Supplement to the 19th Annual Report of the N. Y. State Conservation Department, 1929. A Biological Survey of the Champlain Watershed. 1930.

Shellfish

What has been said with regard to the great destruction of fish is equally true of shellfish. The oysters in Chesapeake Bay were thought to be inexhaustible until they were almost exterminated, when the state of Maryland found that in order to preserve this great natural asset, oyster culture was necessary. Oysters are now conserved here and in other states by cultivation. In certain areas of shallow water old oyster shells, broken stone, or bunches of fagots are placed on which the young, free-swimming larvae may attach themselves. After these "seed oysters" have grown to a sufficient size, they are removed and placed in beds in shallow water, where they are later harvested.

There are two general aspects of the question dealing with the shellfish industry, namely, as it affects marine or fresh-water forms. Among the problems of fresh-water biology those relating to the



Life history of fresh-water mussel.

life history of the fresh-water mussel should be noted.

It is known that the propagation of fresh-water mussels, the shells of which are used in the pearl button industry, depends upon whether the larval stage, or *glochidium*, finds the proper temporary fish host.

This tiny larval mussel attaches itself to the fins or gills of certain species of fish. The host builds a protecting cyst wall about it, when it undergoes further development. After reaching a sufficiently advanced stage, it drops from its host, which by this time may have reached quite a different locality, and continues its own battle for life. The rivers of the mid-west, especially the Mississippi and Ohio systems, are the great producers of fresh-water mussels. The construction of dams and the addition of pollution to these streams have killed off a large percentage of these mussels. Here the United States Bureau of Fisheries came to the rescue and used the fish they were salvaging from the back waters of the Mississippi system as hosts for the glochidia of the mussels. While the effectiveness of this type of

artificial propagation is hard to determine, it is believed that it has been moderately successful. The Bureau is also attempting to raise the glochidia in artificial media in quantities large enough to make it possible to keep the supply from being depleted by the pearl button industry. Here again hope lies in the work of the biologist who must solve the problem.

Birds

In the matter of bird life the story is the same. The American passenger pigeon, which once was so numerous that in 1869 one town in Michigan marketed 11,880,000 pigeons in forty days, became extinct by 1914. In early Colonial times the heath hen was abundant along the eastern coast from Maine to the Carolinas. The last surviving member of this species died on Martha's Vineyard Island in 1932. The snowy egret has been practically exterminated in the South and the prairie chicken has suffered the same fate in the Central West. Unless adequate protection is given, the red-head, canvasback, and ruddy duck may become exterminated at least in parts of their range. The Labrador duck was exterminated in 1875, a victim of reckless exploitation. Measures have been taken to protect the dangerously depleted wood duck, which is now, under a closed season extending over some years in certain states, showing a hopeful though slow increase in numbers.

The relation of bird migration to conservation, as in the case of fishes, is close, for the annual journeys that birds make have been made use of by sportsmen in shooting duck and other wild fowl. While biologists have been trying to explain, with a certain amount of success, the factors back of bird migration, an army of hundreds of thousands of licensed hunters, with very definite success, have been slaughtering migrating birds by millions, until today many of our wild fowl are in imminent danger of extermination. Dr. William T. Hornaday ten years ago estimated that the stock of game birds and quadrupeds left at that time was only about 2 per cent of what had existed fifty years before, and today even this remnant has been greatly reduced. A carefully planned program of restoration of breeding and feeding areas, destroyed by drought, cultivation of the land for crops, or by other agencies, is now being carried out by the Federal government in certain localities in the United States, where not many years ago water and shore birds could be found in great numbers. Sportsmen are combining with agencies seeking a biological approach to the problem.

Mammals

The story is repeated with the mammals. Whales are almost exterminated, whalebone whales for the plates of baleen used in straining out the tiny marine organisms on which they feed, and the right, sperm, and other species for oil. Among rodents the beaver, once having a distribution reaching practically all over the United States north of the Gulf of Mexico and the Rio Grande, is now found only in a few protected areas. They have been practically wiped out because of the value of their fur. Among the carnivores the marten, the fisher, the mink, the fox, and many others wanted for furs have practically disappeared. Even the lion and tiger, with their wide African and Indian ranges, are becoming rarities and are only seen in protected areas. Thus the onward march of civilization ruthlessly exacts its toll.

Conservation of Wild Life

Coming to wild life, we find that efforts toward conservation are still too loosely and ineffectively put forth to be of much avail. There is need for a broad scheme of education that shall reach every part of the country and help to mold public opinion with reference to the conservation of our wild life resources. It is true that as far back as 1884 a start was made by the American Ornithologists' Union to improve the legal status of wild birds. This resulted not only in the formation of the Audubon Society, but also laid the foundation in 1885 for the organization of the Biological Survey along scientific lines of inquiry into the life histories and economic value of birds and mammals. It was not until 1909, however, that the Federal government framed a law, known as the Lacey Amendment, prohibiting the shipping of birds from a state where it was illegal to kill them. In 1913, a Federal law went into effect stopping spring shooting of all migratory birds, and the slaughter of songbirds, including most insectivorous birds. This law gave a closed season on fifty-four out of sixty species of shore birds and shortened the open season on northern waterfowl to three months, all of which has helped greatly, but more especially in the protection of land birds. In 1916, the Migratory Bird Treaty Act with Great Britain was devised and in 1918 signed, protecting over five hundred species of migrating birds in this country and Canada. In 1929, a Federal Bird Refuge Law was passed providing money for the establishment of bird sanctuaries and funds for their maintenance.



U. S. Bureau of Biol. Survey

What are the differences between the bird refuges of the Biological Survey and other Federal agencies? Why are different agencies administering these refuges?

Already over one hundred wild life refuges have been set aside by the Federal Government and these are augmented by many private bird and game refuges and preserves, estimated at the present time to include over 800,000 acres in this country and over 150,000 acres in Canada.

Much also has been done in the way of conservation of mammals. Not many years ago the supply of American buffalo, or bison, was thought to be inexhaustible, but today after *nearly* complete extermination, a few thousand exist protected by law. The Alaskan fur seal is another valuable mammal that was almost exterminated by over-hunting. Great herds were reduced from millions to a little over 200,000 in 1910. At that time the Federal government assumed control, preventing hunting during the breeding season, with the result that today the herd consists of over 600,000 head.

Present Methods of Conservation

Considering in more detail some of the methods used by the modern conservationist, we find that the old hit or miss methods are giving way to new ideas. One method centers about attempts to devise ways of restoring the normal balance of nature, which has been upset

by man's interference, so that reproduction may occur normally. Stocking at random, for example, regions native to grouse and quail with the introduced pheasant, or planting fish in streams without specific knowledge of conditions essential to survival, such as adequate food supply, the effect of climatic extremes of temperature, and protected breeding areas, are seen to be makeshift methods at best, often ill adapted to advance the welfare of either the wild population or of man.

Organizations for Conservation

Through organization, conservation is likely to enter upon a new and more encouraging era. The Wild Life Conference which met in Washington, February 3-7, 1936, had for its purpose the building of a nation-wide organization to undertake the task of a co-ordinated survey of the status of wild life in each state with united support for the enactment or revision of laws devised for the betterment of conditions.

There are many organizations that are interested in the program of conservation. Each state has many different local fish and game clubs that have more or less to do with problems of one kind of conservation. Many of these groups are selfishly interested because as individuals they desire better hunting or fishing. Consequently, the emphasis has been to assist in one way or another in increasing the local output of pheasants or trout. Upon the other hand, national organizations, like the Izaak Walton League, also exhibit an interest in the broader problems of conservation, such as the establishment of game refuges and protection against river pollution by factories and cities.

State Conservation Departments

Local chapters and clubs, whether or not they have national ties, usually work through their State conservation departments, and to a somewhat lesser extent through some Federal agency. The various State departments compile statistics of the vast quantities of fish and game that they have planted. Nearly all of these figures bring out the rather astounding fact that hundreds of thousands of fish and game are planted annually without any appreciable increase in the numbers available for the sportsman and nature lover, and in not a few cases losses are recorded. Nature, even with artificial help in propagation,

does not seem able to hold its own. What happens to all of these animals which are planted and which do not appear to survive?

Biological Surveys

In order to answer this question more intelligently, various scientific studies of one sort or another have been undertaken. Most of these have been aimed at providing an adequate stocking policy for either fish or game. Perhaps the most complete survey of this sort, designed to determine an adequate stocking policy, deals with the waters of New York.

In 1926, the New York State Conservation Department organized a biological survey that undertook over a period of years a most careful study of the various watersheds of the state. The cost of the survey was borne by receipts from fishing and hunting license fees. Practically every phase of the life histories of game fish was investigated. Such matters as the existing fauna of the streams, ponds, lakes, and rivers, together with the food, weed areas, chemistry of the water, extent of pollution, bottom and plankton organisms, as well as the great variety of parasites which infect the fish, were given the most careful consideration. On the basis of the assembled data stocking policies were then determined and some estimate was made of the number and kind of fish which should be planted.

A number of other states have adopted survey programs to help determine stocking and planting policies for fish and game. Both Michigan and California are doing splendid work along these lines and somewhat similar programs are contemplated or are actually under way in other states. The most discouraging feature of such programs is that, in most instances, it is a case of locking the barn door after the horse is stolen, since so much damage has already been done, some of which is irreparable.

Federal Agencies

There are several Federal agencies acting either directly or indirectly along the line of conservation. The Bureau of Biological Survey has various problems under consideration, dealing principally with matters of the migration, distribution, economic value, and life histories of various birds and mammals. In the Bureaus of Plant and Animal Industry centers the work of parasitologists who are concerned with problems of identification and control of various types of plant

and animal parasites. In addition to the field workers, hundreds of research workers in government and state laboratories are investigating problems connected with conservation. Some of these relate to soil, insects, plant diseases and methods of overcoming them, while others are problems requiring a genetical approach. Bacteriologists and plant pathologists are discovering bacteria or fungi that are inimical or restrictive to species of their kind causing damage. An example of such work has recently come from the laboratory of the University of Idaho School of Forestry, where it has been found that the white pine blister fungus, a serious enemy of the white pine, can be destroyed by another fungus which is parasitic upon it. Investigations are only beginning in this fertile field.

The Bureau of Fisheries

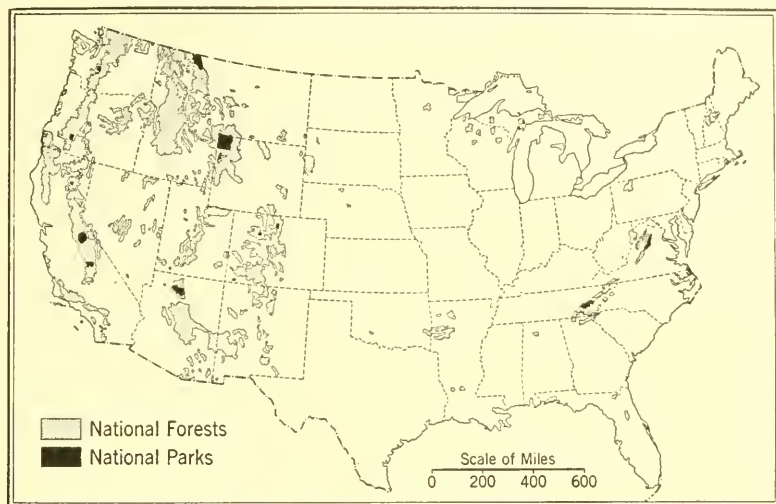
This Bureau is concerned with the propagation of various types of commercial and game fishes, as well as shellfish. During recent years research problems have covered three major fields, marine and fresh-water fisheries investigations, agricultural investigations, and investigations on shellfish.

Under the first heading are studies concerned with the conservation and replenishing of cod, haddock, mackerel, and other salt-water fishes, as well as of trout and salmon, together with various problems relating to other fresh-water fishes. In the second group are the problems relating to the improvement of feeding and breeding trout, the treatment and cure of diseases of hatchery fishes, studies on fish nutrition and investigation of inland waters with respect to pollution. In the third group of investigations is the propagation of the pearl mussels, as well as surveys of the waters in our various National Parks. Fortunately the work of this department appears to be better correlated with the programs of the various State conservation departments than some other governmental agencies.

During the year 1933 a total of ninety-one agencies were concerned with the output of fish for the Federal government. These agencies are recorded as having distributed the astounding number of 7,202,155,600 fish and eggs.

One of the most interesting problems facing the fish-culturist is the question of how many of the planted eggs and fish can survive. Although over 2,000,000,000 artificially fertilized eggs of the cod are released every year, it is doubtful if this helps nature to any great extent. When it comes to the question of stocking with fish eggs,

fry, or fingerlings secured from hatcheries, it is essential that there should be a high survival curve. Recent work tends to show that in the case of trout, at least, the larger the fish, the better the chance it has of meeting and overcoming the vicissitudes of life when stocked in an open stream.



National Parks and National Forests in the United States. How do you account for the geographic distribution of these areas?

National Parks

Among the most valuable Federal agencies for the conservation of wild life are the National Parks, of which there are twenty-two in the United States and eighteen in Canada. In these areas all wild life is protected, including bison, antelope, moose, white-tailed deer, mule-deer, elk, Rocky Mountain sheep, black and grizzly bears, along with numerous smaller predatory animals. National Parks are in the truest sense the pleasure grounds of the conservationist.

Is There a Unified Program?

The thinking American would undoubtedly admit the necessity for a definite long-range plan of conservation for all of our natural resources, regardless of whether or not he is concerned with oil, forests, minerals, or fish and game. Since our various conservation agencies are centered in the Federal government, it is legitimate that

some plan should emanate from this source. The fact is that about fourteen Federal agencies have worked more or less at cross purposes because of the intricacies of red tape, and the results are far from satisfactory.

One agency of the Federal government, for example, reserves a large breeding area such as Tule Lake in northern California for the use of various species of waterfowl. This vast area is the nesting place of thousands of our wild migratory waterfowl, and was set aside for breeding purposes by the late Theodore Roosevelt. A few years ago \$824,000 was allocated to the Reclamation Bureau for the purpose of draining this vast lake and converting it into farm land, the maximum worth of which could not possibly exceed \$300,000. As a result it was reported that in the spring of 1935 agents of the Reclamation Service burned the cattails and rushes along the borders of the lake and literally cooked the eggs in about 800 wild goose nests, — and this to improve the grazing conditions of the region.

Another example of destructive conservation appears in the appropriation of \$200,000 for the eradication of snails in four states of the Pacific Northwest. The purpose of this was the control of the sheep liverfluke. No one denies the desirability of helping the sheep owner with the problem of controlling parasites which do much damage to his flocks. But the method proposed for accomplishing this end is in many respects worse than the disease. The plan called for the placing of copper sulphate, a deadly protoplasmic poison, in the streams of the region. This is an efficacious method of getting rid of snails, but unfortunately it also kills all the other organisms which play such an important part in the economics of stream life.

One of the most disturbing actions with reference to fish conservation is the construction of huge power dams on rivers which are highways for migrating salmon on their way to the spawning beds. Especially is this a serious menace in the case of high dams, where the fish attempt to enter the current flowing from the power plant instead of ascending the fish ladders that are provided, and thus die without being able to deposit their eggs. There is little doubt that the dams now projected in the Columbia River may, within a short period of time, sound the knell of the salmon-fishing industry in this region.

Clearly the answer to the questions raised in the preceding paragraphs can only be furnished by the formation of some Federal Bureau which has the power to regulate all agencies for conservation. The first annual meeting of the North American Wild Life Conference

held in St. Louis in March, 1937, had this end in view and formed the Wild Life Federation. Such a Bureau must have the necessary foresight to enable it to plan wisely and well a long-term conservation program which will meet the ultimate needs of this great country of ours and preserve our wealth of natural resources. Otherwise in the years to come the American people may be looked upon as the greatest "desert makers" of all time.

SUGGESTED READINGS

Hornaday, W. T., *Wild Life Conservation in Theory and Practice*, Yale University Press, 1914.

A fund of information concerning the conservation of wild life up to 1915.

Hornaday, W. T., *Thirty Years War for Wild Life*, Charles Scribner's Sons, 1931.

A valedictory by one of this country's most ardent conservationists.

Pack, C. L., *Trees as Good Citizens*, American Tree Association, 1922.

An interesting and popular account of the value of shade trees, with suggestions for conservation.

Rowan, W., *The Riddle of Migration*, The Williams and Wilkins Co., 1932.

Applications to the conservation of wild birds.

XXVI

MAN'S FIGHT FOR SURVIVAL

PREVIEW. What is health? · What is the biological significance of death? · Causes of disease: Unfavorable environmental factors · Degenerative diseases · Man and his parasitic worms: Parasites acquired through improperly prepared foods; parasites acquired directly by man; parasites acquired indirectly by man; malaria as an economic problem; yellow fever and its relation to insect vectors; typhus; other diseases carried by insects; animals other than insects may spread disease; the relation of bacteria to disease; certain bacteria, called pathogens, cause disease; how do bacteria enter the body? some important bacterial diseases · What is immunity? The mechanism of immunity; active acquired immunity; some examples of diseases where active immunity is practiced; bacterins and their use; the menace of the carrier; vaccines and attenuated organisms; hay fever; passive acquired immunity · Are parasitic diseases conquerable? · Suggested readings.

PREVIEW

The growth of knowledge of man's relation to parasites and the prevention of disease has been a matter of evolution. Primitive man used charms and incantations to ward off disease. During Roman times traditional methods were handed down from the Greek and Roman philosophers. The first glimpse of real knowledge came in the seventeenth century with such discoveries as that of the circulation of blood by Harvey, the relatively modern diagnostic work of the physician, Sydenham, and the surgical skill of John Hunter. In the eighteenth century progress was marked by the work of Jenner in relation to vaccination for smallpox. In the nineteenth century a rapid advance began with Pasteur's discovery of bacteria as one of the causes of disease, the isolation of some of man's most deadly enemies by Robert Koch and others, and the foundation of modern antiseptic surgery by Lister. During the latter part of this period many discoveries of ways and means of disease prevention were made, such as the beginnings of water filtration, the pasteurization of milk, and more emphasis on the control and prevention of various diseases. The twentieth century marks a notable departure into the field of public health and a rapid development of public health work.

The discovery of the importance of disease carriers, both insect and human, has played an important part in the improvement of living conditions, while even more important is the advance of knowledge in relation to immunity and the factors which bring it about. The life span has steadily advanced as a result of these and other discoveries and their applications, a gain brought about largely through the mastery of disease caused by bacteria, especially those diseases which are fatal to young children.

Since the question of the survival and progress of civilization depends upon a knowledge of the means of successful control of disease and preservation of health, a study of man's fight for survival should be of the greatest value to college students, who later must take their places as intelligent citizens and voters. Upon their knowledge of the facts concerning the successes in this battle against parasites and disease, further progress will depend.

Although our knowledge should be preventive rather than curative, since it is the duty of the physician to take care of the disease when it comes, the average citizen ought to be well informed enough to answer all of the following questions intelligently. What are the causes of disease? Which parasites do man most bodily harm? Where is he most likely to meet them and how may he prevent their attacks? What are the facts about human carriers? Do present laws adequately protect man against them? What is natural immunity and how does the body protect itself? What is the present status of protective immunity and what are the ways in which man may bring it about? These questions are taken up in the pages that follow.

What Is Health?

Health is evidently something to be sought after as a primary objective of life. The old Anglo-Saxon word, *hoelth*, from which the word *health* is derived, meant *whole* as opposed to its opposite, *socc* which meant sick or not whole. The implication is clear. Health is a condition in which body and mind are free from disease. One writer puts health on a higher plane and defines it as "the quality of life that renders the individual fit to live most and serve best."¹ Such a definition gives to life a higher responsibility, and is one that should be adopted by every man and woman. If education

¹ Williams, J. G., *Personal Hygiene Applied*, Saunders, 1926.

means leadership, then it should mean healthy leadership in the best sense.

The human body has been likened to an engine by many writers. It requires fuel and oxygen in order to release energy, forms wastes which have to be eliminated, and must have frequent rest in order to do its work most efficiently. Both machine and body eventually wear out, but we do not refer to a sick machine although we do speak of a sick person. Anyone may abuse his body through lack of sleep, exercise, or improper food so that it will not function properly. He may poison it with alcohol and nicotine and injure some of the internal organs so that they never will have their former efficiency. He may meet with an accident and be crippled, or he may be attacked by microscopic foes such as bacteria or protozoa and thus suffer from disease. Not only in these respects does the body differ from the machine, but also for the reason that it can repair itself, a thing which no machine can do. When it is in perfect condition it is called a healthy body.

What Is the Biological Significance of Death?

In old age, the body machinery begins to wear out, the normal functions slow down, tissues wear away, the liver, kidneys, reproductive and nervous tissues shrink and cease from more active functioning. Muscles lose their tone, the weight becomes less, special sense organs lose their accuracy as the body reacts more slowly to stimuli and the skin does not shrink as fast as do the tissues beneath. Digestion does not function as well as formerly and apparently there comes a slow poisoning of the tissues, since the cells give out wastes more rapidly than they are eliminated. The body machine wears out because it cannot eliminate the poison fast enough. At length some part of the system gives out. In most cases the muscles of the heart, that have been constantly at work since before birth, suddenly stop, or the arteries, which have become brittle through faulty calcium metabolism, break and death ensues.

We often think of an animal as dead if its head is cut off. But under such circumstances the heart of a frog or a snake continues beating. Obviously such an animal is not all dead. The work of Carrel with excised tissues gives evidence that the individual cells of the body, if in a favorable environment, will continue living perhaps indefinitely. Physically, death means the breaking of the plasma membranes of the cells so that their selectively permeable properties

are lost. When a cell is killed, substances which in life could not pass in or out by osmosis can easily do so, with the result that it loses the salts and sugars essential for life, as well as its turgor, and becomes limp. It is dead, for it no longer has the ability to regulate its outgo and intake.

Causes of Disease

The causes of disease are many. These may be listed as food deficiencies, endocrine maladjustments, hereditary deficiencies, unfavorable environmental factors, bad health habits which result in body poisons, diseases of middle and old age (wearing out of the machine), parasitic diseases, and infections. Health examinations of some 1500 men entering Cornell University showed that over 50 per cent had defective eyes, over 25 per cent bad posture, over 22 per cent skin disease, 22 per cent enlarged thyroid glands, and over 20 per cent flat feet, all of which physical handicaps are correctable.¹ Wood's estimate made in 1918 of 16,000,000 school children with physical defects or ailments either preventable or remediable has not changed greatly in recent years. These conditions in children and young adults are largely due to lack of proper care in running the human machine. Improper diet, overfatigue, poor posture, overstimulation through drugs or alcohol, heedlessness of warning symptoms — these are the most frequent causes of bodily illness. Dr. Vincent, former president of the Rockefeller Foundation, recently stated that more than 80 per cent of the illnesses of man could be avoided if people were willing to obey the laws of health and live as well as they knew how to live. The running of the human machine is up to the individual and it is only through his willingness to take care of himself that an individual health program can be established.

Unfavorable Environmental Factors

In the past this factor has been overstressed. There is no doubt that overcrowding, unsanitary conditions, and lack of a pure water supply help to raise the death rate. Tuberculosis, for example, is closely correlated with social conditions. Factors which lower the bodily resistance also, such as fatigue, exposure to conditions of wet and cold, poor ventilation in working and living quarters, are all menaces to health, but the old idea that the products of decomposition of animal and vegetable material cause disease is untrue. A few

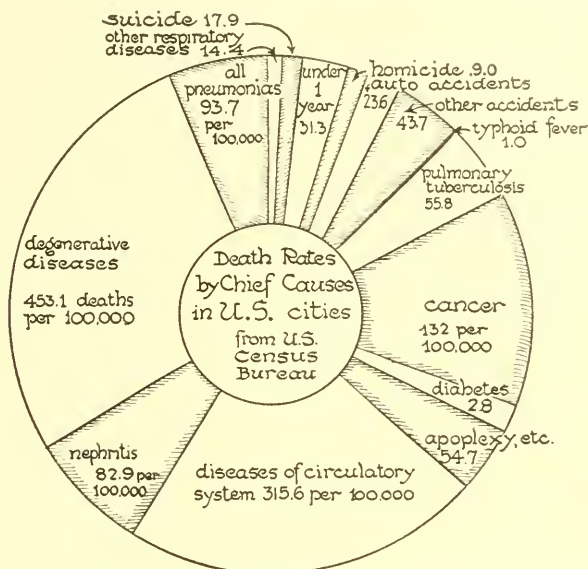
¹ Smiley and Gould, *A College Textbook of Hygiene*, Macmillan, 1926, p. 3.

decades ago, interest centered in civic clean-ups because it was believed that clean streets meant a lower death rate, but street cleaning or house cleaning will not control epidemics of disease. On the other hand, there are unfavorable environmental factors which directly contribute to outbreaks of epidemics, such as impure milk and polluted water supply, the control of which is of the utmost importance to the health of the individual. Not only food supplies containing the proper vitamins necessary to life are essential to health, but also the assurance that all foods handled are clean and that the handlers of foods are also clean and free from disease. Selfishness of neighbors is a large factor in the health of a given community, since communicable diseases are spread through carelessness on the part of those who have them. The publicity of scientific knowledge is a large factor in public health. The increase of interest on the part of the public is today correlated with clinics for the care of babies, for prenatal care, for the care of venereal disease and tuberculosis, and above all with clinics where treatment for immunity against certain diseases may be received. Health knowledge disseminated by means of bulletins, lecture bureaus, radio talks, and particularly school health programs and public nursing services, are all factors which help to control unfavorable conditions in a given community.

Degenerative Diseases

After the age of forty, the greatest number of deaths are caused by heart disease, cerebral hemorrhage, arteriosclerosis, cancer, paresis, and nephritis. Along with these, pneumonia and tuberculosis claim many victims. The statistician, Louis Dublin, states that approximately 2 per cent of the total population of the United States suffer from organic heart defects and that the number of deaths from this cause is over 200,000 annually. It is the chief cause of death after the age of forty-five years. The origins of this disease often date back to childhood, when heart lesions may have resulted from early infections. A large percentage of heart trouble is also due to syphilis. In the case of cancer there is a constantly mounting mortality. We know what cancer is, but we do not know what causes it. Apparently certain groups of cells go wild, growing without restraint until they destroy their victim. Two types of cancer are known, only one of which is malignant. Education ought to make people realize the necessity of immediate diagnosis and an operation, when necessary, if cancer is to be overcome. Nephritis, a disease of the kidneys, slows

down their efficiency, allowing poisons to accumulate in the body which eventually cause death. In the case of cerebral hemorrhage, as well as apoplexy and arteriosclerosis, the only help comes in



Death rates in cities of the United States, based on the latest available information. What types of diseases exact the greatest toll of life?

moderation both in diet and in bodily activity. Degenerative diseases are the natural result of the gradual wearing out of the body and all that we can expect to do is to lessen the death rate from these causes.

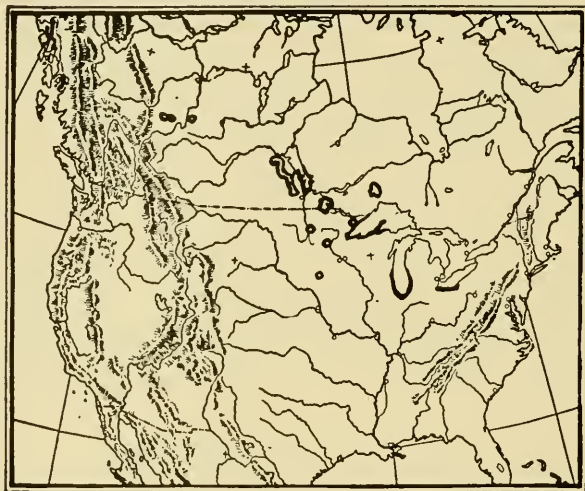
Man and His Parasitic Worms

Various parasitic worms have been known for countless centuries as enemies of man. In the Ebers papyrus of the sixteenth century B.C. there is a record of certain diseases attributed to the presence of the "bowel worm." The fiery serpent which the Israelites encountered in the wilderness of Sinai was undoubtedly none other than a round-worm, *Fullebornius (Dracunculus) medinensis*. Evidence of the sagacity of Moses lies in his separation of animals into "clean" and "unclean" on the basis of the presence or absence of parasites. Thus all scavenger beasts were prohibited as food. As civilization progressed and man used more cooked food, the number of parasites

which could be acquired through the ingestion of raw meats was much reduced. However, there are still epidemics of various parasitic diseases due to worms, although they usually occur in widely scattered localities.

Parasites Acquired through Improperly Prepared Foods

Fortunately there are only a few tapeworms which may affect the health of human beings. Meats that pass from one state to another are inspected by the Federal government for the presence of larval stages of such parasites. Not all beef and pork, however, is examined for the encysted larval stage of the beef and pork tapeworms (*T. saginata* and *T. solium*). This means that meat obtained through local abattoirs would not be inspected by a Federal representative and so might be infected. The descriptions of the life



Regions in North America where fish infected with the larval stages of the broad tapeworm of man have been taken. (After Ward.)

histories of these worms, as well as that of the broad tapeworm of man (*Diphyllobothrium latum*), are found on pages 226-230.

A study of the distribution of the broad tapeworm in the United States suggests that it was introduced from the continent by various immigrants who were infected when admitted to this country. A very high percentage of the population living near the shores of the Baltic Sea, like the Finns, are infected with this tapeworm. One of

the first endemic centers of the broad tapeworm of man in this country was in the region in and about Ely, Minnesota, which is a community with a high percentage of Finns. More recently, the parasite has been found to be spreading to other parts of the country and it is possible that it may prove to be one of the more important parasitic worms with which health authorities have to deal, since both of the intermediate hosts are found in nearly all of our inland waters.

Another parasite that is perhaps the most universally distributed form in this country is the pork roundworm *Trichinella spiralis*, an organism so minute that the government does not take the responsibility of inspecting for it. Great care should be exercised in preparing pork to have it *thoroughly* cooked. The life history of this worm is described on page 225.

The presence of the larvae of *Trichinella* in the blood stream stimulates the production of one group of white blood corpuscles, the *eosinophils*, which is a characteristic symptom of trichinosis, as this parasitic disease is called. At the time of the penetration of the larvae into the muscles, severe muscular pain, especially in the extensors and flexors, is usually experienced, which is followed by a period when the patient becomes emaciated and anemic, and is frequently succeeded by a secondary complication in the form of pneumonia. Death may ensue due to exhaustion or pneumonia.

On the basis of 1895 autopsies made between 1881 and 1910, 39 (2.5 per cent) were infected with *Trichinella spiralis*. More recently Queen (1931) reported a total of 18.6 per cent in 403 autopsies and Hall (1936), 13.7 per cent. This does not necessarily mean that trichinosis is on the increase in this country but rather that the methods of detection have improved, more representative samplings of the population have been made, and that the examinations are more careful. It appears probable from the above that a much greater proportion of the population harbors this parasite than was previously supposed.

Parasites Acquired Directly by Man

There are several rather important parasites of man found in this country that are not carried by an intermediate host, but which reach him directly. The two most important forms are the hookworm (*Necator americanus*) and the roundworm, *Ascaris*. Children frequently pick up other parasitic worms, but these two are probably the most important from the standpoint of public health.

The hookworm was first recognized as an insidious cause of disease in this country by Dr. C. W. Stiles in 1902. He considered it a major factor responsible for the condition of indigent and shiftless people known as "poor whites" throughout the southeastern part of the United States. Infection by hookworm has recently been found to be almost universal in some tropical countries and is widespread in all tropical countries at the present time. The Negro is apparently much more resistant to the debilitating effects of this parasite than his white brother. The survey work of the Rockefeller Sanitary Commission has made it possible to follow the progress of educational campaigns throughout the world to combat hookworm disease as well as to study the effects of the treatments administered for its suppression. Between 1910 and 1915, a survey was conducted in the United States under the auspices of this commission and it was found that children between six and eighteen years of age carry the heaviest infection. Of approximately 90,000 children examined, 55.1 per cent were infected. Between 1920 and 1923, an inspection of more than 44,000 children from some of the same areas showed that the infection had dropped to 27.8 per cent. In this same connection it should be noted that the infection was also much lighter, some school children harboring but few worms.

The question arises as to the way in which the infection becomes established, and how it happens that children are more heavily infected than their parents. The fact that youngsters are usually barefoot while a much greater proportion of the adults wear shoes has a direct relation to the spread of the infection. The control of the hookworm is due largely to education in community sanitation in addition to therapeutic measures. In the poorer districts of the South, sanitary privies were rarely found, hence the soil in many localities was literally alive with hookworm larvae. With the building of privies and educating people, both young and old, to wear shoes as a means of prevention, the danger of infection in these regions was greatly decreased. Several substances have been used as vermifuges, carbon tetrachloride in a chemically pure form having been found most efficient.

In foreign tropical countries aid given to over seventy different countries or states through the International Board of the Rockefeller Foundation has reduced hookworm infection on an average of 50 per cent in Ceylon, India, the Philippines, and Siam, as well as in some South American countries.

Another parasitic infection caused by the roundworm *Ascaris lumbricoides* involves a rather large proportion of the population, especially in the southern parts of this country where the weather is warmer and presumably the conditions necessary for its development are more nearly ideal. Prior to 1921 various surveys indicated that the eleven states extending east of the Mississippi River and south of the Ohio, with Texas, had an average infection of 13.8 per cent of the population. Further studies were carried on in 1934 with the result that certain regions in mountainous sections where soil conditions were just right for its spread showed an infection rate as high as 30 per cent. However, it was demonstrated that through the use of suitable sanitary methods this worm can be controlled, as seen by reference to its life history, page 225.

Most of the parasites mentioned which infect man are intestinal forms. In the midwest, however, bathers at a few summer resorts have encountered a different variety. Certain fork-tailed free-swimming larvae, *cercariae*, of some of the blood flukes which normally penetrate the skin of some of the lower mammals to invade their blood streams apparently mistake man for their normal host. Fortunately they do not continue their development in this unusual host, although causing an intense itching during and after penetration of the skin, chiefly among susceptible people.

Parasites Acquired Indirectly by Man

In the higher as well as in many of the lower organisms which parasitize man, the life history of the invader is often found in two or more different hosts. Contact with the parasite, obviously, is necessary in order to have the disease germs enter the body.

In the case of protozoan parasites which affect man and in some cases of bacterial infection a carrier usually becomes necessary in order that the infective organism may reach the interior of the body. Among these carriers there are two

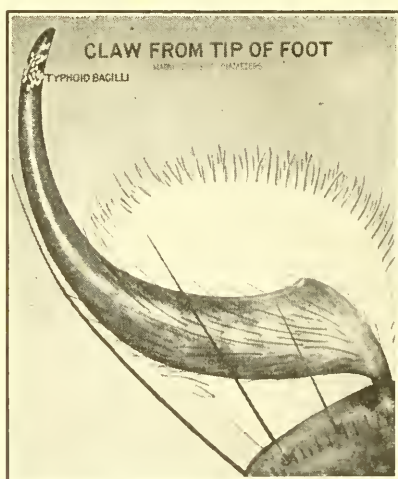


Diagram to show how bacteria might be carried on the foot of the house fly.

distinct types. In many cases insects, that are called *vectors*, pick up the destructive organism incidentally and carry it. Such an insect carrier is the house fly, which has been inveighed against by many writers as being one of our most deadly enemies as a carrier of intestinal diseases.

Many other insects have criminal records of this sort, for example, the malarial organism is carried by a specific mosquito, *Anopheles*. Yellow fever is directly related to the *Aedes* mosquito, while in the Far East another species carries the filarial worm, which causes the terribly deforming disease known as *elephantiasis*. In certain areas in Africa, the tsetse fly *Glossina* transmits the dreaded sleeping sickness, and almost universally lice, fleas, ticks, and mites may all be added to the list of organisms responsible for spreading disease.

Insects that carry parasites dangerous to man's health and welfare may be divided into two groups, first, casual carriers, such as the house fly, in which the parasite carried has no relation whatever to the life of the insect carrier, and secondly, predatory insects, or those which suck blood, and in which the parasite passes a part of its life cycle. Such insects may often be dangerous carriers, as shown by the blood-sucking mosquitoes that carry malaria and yellow fever.

Malaria as an Economic Problem

The economic problem of malaria has been very serious in almost all temperate and tropical parts of the world. In this country, the problem has affected over 13,000,000 of the inhabitants, principally those living in the South, where in some states as high as 90 per cent of the population live in districts where the malarial mosquito is normally found. Statistics in this country show that millions of dollars are lost each year through workers who are incapacitated and whose efficiency is materially affected by the disease. It is estimated that for each death attributable to malaria there is a loss of from 2000 to 4000 days by illness.

Among the effective preventive measures are oiling of standing water to prevent breeding of mosquitoes, draining of marshes, the introduction of certain species of fish which feed upon the larvae, and screening of houses in districts where malaria is present. The most recent method of control is by spraying standing water with finely powdered Paris green. The anopheline larvae eat this material and are poisoned by it. In some parts of Italy where malaria has been extremely prevalent in the past, it was found that towns in areas

where the Paris green treatment had been used have almost completely eliminated malaria, while in towns only a few miles away where no such treatment was used, four fifths of the inhabitants contracted the disease in a single season.

Yellow Fever and Its Relation to Insect Vectors

Although we do not think of yellow fever as being an important disease today, it was not more than a century and a half ago that it played a very important part in the health of this country. As late as 1878, the disease ravaged the Mississippi Valley, where in 34 cities there were nearly 70,000 cases and over 16,000 deaths.

The story of the conquest of yellow fever is one of the most thrilling in medical annals. After the Spanish-American War, when yellow fever was so prevalent in Havana, a military commission consisting of Major Walter Reed, James Carroll, A. Agramonte, and Jesse Lazear was established to investigate the control of the disease. After a series of experiments which resulted in the death of Dr. Lazear and the severe illness of several army volunteers, the mosquito *Aedes* was proven to be the carrier of this dread disease. Methods of prevention adopted as a result of these experiments were almost immediately successful in Cuba and in other parts of the world where the disease had been endemic. Yellow fever has always been limited to areas near the seacoast or along the banks of navigable rivers. It is prevalent during hot seasons, but much less of a menace in cold weather. Now that we know the relation of the disease to its transmission by the mosquito *Aedes* some of these points clear up.

No one has yet seen the causal agent of the disease. In 1918 the Japanese parasitologist, Noguchi, working for the Rockefeller Institute, found a spiral organism which he believed was the cause. Later he lost his life on the Gold Coast of Africa while still seeking the causal agent. It is now believed that the organism is not a spirochete, but a filtrable virus. Even though the organism is not known, the fact that the carrier is has made it possible practically to eliminate the disease from areas where as late as 1900 it was endemic.

Typhus

Another disease closely connected with an insect carrier is typhus. During the seventeenth and eighteenth centuries epidemics of this disease were frequent in crowded and unsanitary areas, especially

where conditions of famine and war were found. In 1909, the transmission of typhus was first correlated with the bite of the body louse or "cootie." During the World War the disease was kept under control through the disinfection not only of wearing apparel but also of the soldiers themselves in "de-lousing" plants which were established back of the front-line trenches.

Other Diseases Carried by Insects

Numerous protozoan diseases are carried by insects. In tropical countries, especially, several diseases of cattle as well as of man are caused by *trypanosomes*, tiny protozoans belonging to the group of the flagellates. One species (*T. gambiense*) produces the African sleeping sickness while another form (*T. cruzi*) causes Chagas' disease in South and Central America.

Many other diseases of man are caused by parasitic protozoans. Amebic dysentery is caused by the presence of *Endameba histolytica*, which lives in the colon of the digestive tract. These parasites are much more widely spread than was formerly thought, for even in this country from 5 to 10 per cent of the population carry this parasite. Amebic dysentery received considerable publicity during the recent World's Fair at Chicago when several carriers were discovered handling food and a number of cases were traced to Chicago. Among other insect-borne diseases are *kala azar*, a tropical fever, which is thought to be carried by fleas and bedbugs; *dengue*, a disease caused by a filtrable virus carried by mosquitoes; *pappataci*, a tropical disease believed to be caused by a filtrable virus and carried by a sand-fly; and possibly *poliomyelitis*, which is thought to be carried by flies.

Animals Other Than Insects May Spread Disease

The arachnids or ticks are serious enemies of higher animals, especially cattle, because they transmit such diseases as Texas fever, and in the case of man, the Rocky Mountain spotted fever. The relapsing fevers of the tropics are also believed to be carried by ticks as well as by bedbugs, fleas, and some biting flies.

Bubonic plague, the Black Death of the Middle Ages, is estimated to have killed over 25,000,000 people in Europe during the fourteenth century. It even reached this country about 1900, killing more than 100 persons in California during the succeeding four years. At present, there are several endemic foci of the disease, one in China, one

in India, a third in Arabia, and a fourth in the interior of Africa, to which must now be added a fifth area on our western coast. Plague is really a disease of rats and ground squirrels, but through the activity of fleas it can be transferred from a sick rat to the body of man, where it thrives. Over a million rats were killed in fighting the last outbreak of bubonic plague in California and great care has to be used in quarantine to prevent rats from reaching our shores through ships from countries where the plague is endemic.

The Relation of Bacteria to Disease

Bacteria are present almost everywhere as parasites. They are found inside as well as outside of the human body, existing in countless millions in the mouth, on the teeth, and particularly in the lower part of the food tube. There has been a good deal of discussion as to whether the bacteria in the food tube are harmful or useful. Experiments indicate that in some animals, at least, bacteria live as mess-mates in the digestive tract, actually helping the host by breaking down waste from foods. Several recent experiments have shown that intestinal bacteria are not necessary, however, in the life process of the host.

Certain Bacteria Called Pathogens Cause Disease

These organisms, like other living things, take in food and form organic wastes within their own bodies which they give off as toxins. Toxins that diffuse through the body tissues of the host where the infection occurs are called *exotoxins*, while those retained within the bodies of the bacteria to be released at their death are referred to as *endotoxins*. Every species of pathogenic bacteria forms a particular toxin which has a specific action on the host, frequently causing symptoms of a definite disease. When bacteria die, as they may in great numbers during the progress of a disease, they break down, releasing protoplasmic constituents that separate from each other, splitting into smaller and smaller molecular groups as proteins do when changed to amino acids during digestion. These *split proteins*, as they are called, may be extremely poisonous and act in many cases as toxins. Bacteria also break down body tissues of the host, in some cases destroying the intestinal lining, blood corpuscles, or, as in tuberculosis, definite tissue cells. Parasitic bacteria that cause boils and abscesses are believed to send out enzymes which dissolve the white corpuscles so that they may be used by bacteria.

Like other parasites that have been mentioned, bacteria show considerable variation as to choice of host. Some few, such as those causing typhoid, Asiatic cholera, or syphilis, are restricted to man and apparently cannot gain and maintain a hold in the bodies of other hosts. Another group, bubonic plague, anthrax, rabies, and glanders, that normally live in other hosts than man, have become adapted to his body through his contact with lower animals. One of the best examples of accidental parasitic attack on man is bubonic plague, which came through the introduction of the rat as a hanger-on in homes. A third group of bacteria which includes the tubercle bacilli as well as the group of the streptococci and pneumococci appear to live in several different hosts. Certain of the cocci are parasitic in other animals as well as in man. The bovine tubercle bacillus may live in the pig or in man as well as in its original cattle host. It was this habit among certain types of bacteria of living in a variety of hosts that gave the clue to some of the early discoveries with reference to disease. Robert Koch noticed, for example, tiny rods in the blood of sheep that had just died from splenic fever. He could not afford to purchase sheep to experiment with since he was a poor country doctor, but he could afford mice. He found that inoculations of the mice with infected sheep's blood caused the death of the mice and, moreover, that the same symptoms appeared in both mice and sheep. This fact led to the discovery, through the making of pure cultures, that one specific germ causes the disease *anthrax*. Many other similar discoveries have hinged on the biological factor.

How Do Bacteria Enter the Body?

Microorganisms causing infectious diseases enter the body through some body opening, respiratory, digestive, genital, or urinary, or through wounds in the skin. The most frequent means of infection is through direct contact or by a spray of tiny droplets which is expelled into the air while talking. Other avenues of infection are dust, which spreads germs of tuberculosis; impure water or contaminated milk, which may contain typhoid germs; soil, from which the tetanus bacilli may be picked up; raw foods, which may spread such diseases as septic sore throat and typhoid; and handling of articles used by persons suffering from an infectious disease. In addition to these means there is the introduction of infection through carriers, such as insects or, in some cases, man. The human carrier, as we will see later, is a most serious menace to society.

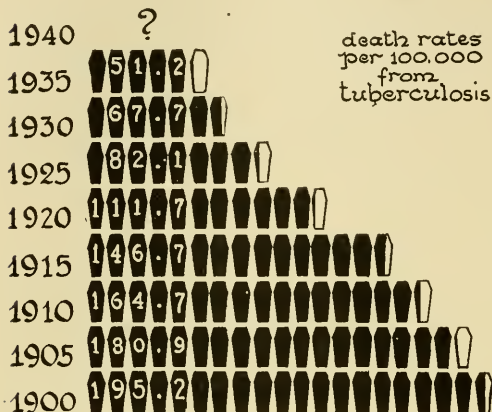
It might be thought that with all of these bacterial foes and so many means of infection the human body would succumb without even making a fight. However, man has several definite ways of resistance. In the first place a good state of health does much to give effective resistance to entering bacteria. The skin, if healthy, is an effective barrier and is far more effective if it has no abrasions. Many secretions given off from the protective tissues, such as tears which cover the conjunctiva of the eye, the various juices of the digestive tract, and even the lymph that surrounds the body cells, contain resistive substances that prevent the growth of bacteria, *provided* the body is in a healthy condition.

Some Important Bacterial Diseases

Although modern medicine is rapidly conquering many diseases, some still remain unvanquished. Of these, tuberculosis stands out as one of the most serious enemies of man. While the common cold causes more days of illness and is perhaps economically the most important, it is not as serious a menace as tuberculosis, which is probably responsible for one tenth of all the deaths due to diseases to which man is subject. In 1900, the death rate from tuberculosis was 195.2 for each 100,000 inhabitants in the registered area of the United States. In 1935, the death rate in the same area had dropped to 51.2 per 100,000. While this is encouraging in the extreme, it does not mean that the disease is conquered.

Tuberculosis is caused by the growth of tubercle bacilli within the lungs or other tissues of the body. In the lungs they form small tubercles which close up the delicate air passages, while they also attack other parts of the body, causing tuberculosis of the bones, scrofula, and other diseases. Tuberculosis is usually contracted from other people who have the disease, although in the case of children the bovine tuberculosis germ may cause the disease. Dr. William H. Park, a noted authority on bovine tuberculosis, states that in a very large number of cases investigated, 57 per cent of abdominal tuberculosis in young children and 47 per cent of such tuberculosis in children under five years of age was of the bovine type. It is needless to say that all milk should come from tuberculin-tested cows or at least be pasteurized, especially if the milk is of doubtful origin, since this method, if properly used, will kill the tuberculosis germs. About one per cent of the beef cattle show tuberculosis by test, but the meat from such cattle, if properly cooked, is not a menace.

Tuberculosis is unfortunately tied up with social conditions and for this reason is extremely difficult to combat. Ten times as much tuberculosis has been found in the heads of families earning less than \$500 a year as among those earning \$700 and over. The



What factors are responsible for the steady decline in deaths from tuberculosis?

disease is not inherited, but where people live crowded together with other tubercular people, it is extremely hard to prevent infection, especially if they live in homes with little ventilation. In New York City there formerly existed blocks of tenements which were known to the health authorities as "lung blocks" because tuberculosis existed there year after year. Tuberculosis

is also closely related to certain trades, especially the so-called dusty trades. Any work that lowers the resistance through poor ventilation, long hours, insufficient nutrition, and dusty occupations paves the way for tuberculosis. The chief factor in combating tuberculosis is keeping up a high resistance to all diseases. This is obtained only through proper amounts of sleep and rest, plenty of fresh air, proper food with a large amount of milk, and, particularly, freedom from worry. Since all of these conditions are difficult to obtain in the lower social scale, it is obvious why the disease is so hard to combat. A form of vaccination, the Calmette vaccine, is now being used with some degree of success, especially in the case of young children.

In the year 1920, influenza and pneumonia were responsible for twice as many deaths in the United States as were caused by tuberculosis. Those of us who remember the frightful epidemic which lasted from September, 1918, to June, 1919, have reason to dread influenza. There have been over fourteen epidemics of influenza and pneumonia since the sixteenth century. In the great outbreak during the World War there were 635,000 deaths from these diseases as against a normal mortality of 135,000 for the same period. Of a total population of

104,000,000 in this country, it is estimated that over 30,000,000 had influenza. While much work has been done to discover the causative organism of influenza, the fact that the organism works in conjunction with several others, including the pneumococcus germ, has made it difficult for the disease to be fought by means of vaccines or immune sera. At present these two diseases may be named among the most serious enemies of mankind.

Although it is impossible to do more than mention the many diseases caused by bacteria, emphasis should be placed on the fact that among the most common infections are those caused by the *Streptococceae*. Pneumonia, septic sore throat, which often appears in severe epidemics, erysipelas, and apparently catarrh and some forms of colds are caused by them. The *Staphylococci* are responsible for boils and abscesses. A member of the genus *Neisseria* causes gonorrhea and probably cerebro-spinal meningitis. Anthrax, tetanus, whooping cough, gas gangrene, cholera, bubonic plague, Malta fever, one type of dysentery, and hundreds of other diseases are due to specific forms of bacteria.

What Is Immunity?

It is a matter of common knowledge that certain members of a family will have a very light attack of a communicable disease while the others may suffer severely from it. Some may be exposed many times to a given disease and not take it, while others, who are more susceptible, will come down with the disease. This resistance on the part of the body to disease is called *immunity*. Adults are practically immune to certain children's diseases, such as measles, chicken-pox, and scarlet fever. On the other hand infants appear to be immune, especially early in life, to both diphtheria and measles. A theory has been advanced that this early immunity is restricted to breast-fed babies because the material (*colostrum*) secreted in the mother's breasts shortly after childbirth contains substances which protect the child against these and other early infections.

Eskimos, Indians, the Irish, Scandinavians, and Negroes are very susceptible to tuberculosis, while Jews are relatively immune to this disease, probably due to the fact that the American Jews have lived an urban life where they have been constantly exposed to tuberculosis and so have built up an immunity to it. The inhabitants of the Fiji Islands were almost wiped out by exposure to measles, a relatively mild disease to the European. The Negro seems to have a natural

immunity to diphtheria, while the North American Indian is somewhat immune to scarlet fever. The natives of South America are much more resistant to malaria and yellow fever than are whites from more northern territories. Evidently, then, immunity may be *racial* as well as *individual*.

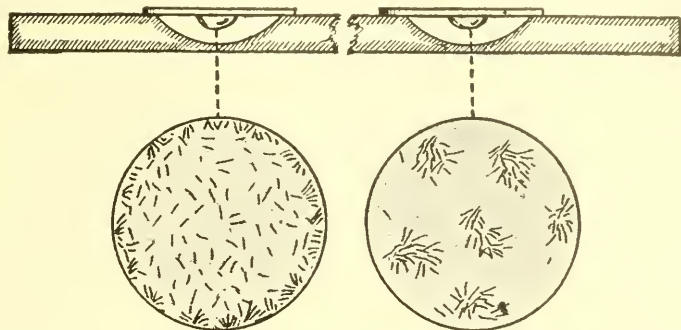
Immunity is also brought about through an attack of infectious diseases. One Greek historian who visited Athens more than twenty centuries ago noted that those who recovered from a visitation of plague did not take the disease a second time. Immunity which lasts for a greater or lesser period is usually found after attacks of smallpox, chicken-pox, measles, mumps, scarlet fever, whooping cough, and many other diseases.

The Mechanism of Immunity

All toxins, when entering the human body, cause the body cells and blood to react to these poisons, through the protection of various substances known as antibodies. These, when produced in the body, have the effect of either neutralizing the toxins or actively fighting bacteria. In addition to antibodies there is also a protective mechanism (*phagocytes*) in the white corpuscles of the blood. If bacteria get into a wound, for example, the phagocytes are apparently drawn to the spot, possibly through some chemical stimulus, and attack the bacteria by engulfing them. The blood contains certain types of antibodies which are known as *opsonins*. These, which are specific for different diseases, enable the phagocytes to engulf and digest invading bacteria.

Certain other antibodies called *lysins* act directly on the bacteria themselves, causing them to dissolve. Still another group of antibodies called *agglutinins* cause the bacteria in the blood to clump together in tiny inactive masses and are doubtless acted upon by both opsonins and lysins so that they become an easy prey for the phagocytes. Yet another group of antibodies, known as *precipitins*, cause the bacteria to precipitate out from the blood in masses that are easily discernible under the microscope. Agglutinins and precipitins have become of great value to physicians in determining whether or not certain diseases are present. For example, a test known as the *Widal* test has been developed to determine whether a person has typhoid fever. A few drops of the patient's blood are allowed to stand until the serum has separated, and this is then diluted with a weak salt solution to which are added live typhoid bacteria. If the

person whose blood is tested has typhoid, the bacteria will immediately become clumped together or agglutinated, thus showing that



Agglutination test for typhoid. The diagram at the left shows free-swimming bacteria, at the right the bacteria have become clumped together by the agglutins produced by the body cells.

the antibodies are already formed and are at work. Just as each disease is caused by a specific kind of organism producing a specific type of toxin, so the blood forms a specific type of antibody for each toxin.

Another method of receiving immunity has been recently discovered independently by two investigators, Twort and d'Herelle. The latter made a suspension of feces from a convalescent case of dysentery, filtered the material, and then added the filtrate to a broth culture of dysentery and found that some substance in the filtrate killed the bacteria. This substance he called *bacteriophage*. It is ultra-microscopic, specific, being produced by specific bacteria, and appears, under certain conditions, to produce immunity to specific diseases.

Active Acquired Immunity

It has long been known that immunity can be acquired through an attack of a given contagious disease. The idea underlying this type of immunity, later developed by Pasteur, is that the causal organism may be weakened, then inoculated into a person's body, and a slight attack of the disease thus induced. Active immunity is now brought about in different ways through the introduction of (1) living organisms causing the disease, (2) attenuated or weakened organisms, (3) dead organisms, or (4) extracts of products of the organism. All of these substances may be called *vaccines*. The underlying prin-

ciple in this type of immunity is the same in all of these cases. Certain cells of the body are roused or activated to form antibodies. Thus the invading organisms are destroyed and their toxins neutralized. In other words, the body is active and does its own work by means of lysins, precipitins, agglutinins, and other defense mechanisms.

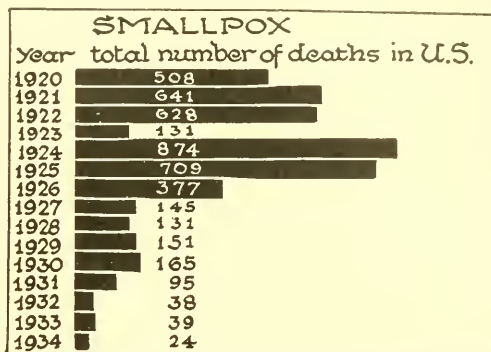
Some Examples of Diseases Where Active Immunity Is Practiced

Smallpox is a very ancient disease, having been known for thousands of years. Always epidemic, in the eighteenth century it is said to have caused 60,000,000 deaths in Europe. The disease was brought to America by the Spanish early in the sixteenth century, and three and a half millions of Mexicans died as a result. The American Indians were almost wiped out by epidemics of smallpox that began in early Colonial days.

The famous discovery of vaccination for smallpox by Edward Jenner was a matter of evolution. The Chinese and Turks used a form of inoculation against smallpox. Lady Mary Wortley Montagu, a famous beauty of her time, and wife of the English minister to Turkey, believed so much in the inoculation practiced by the Turks that she had her own boy inoculated and introduced the practice into England in 1721, a date considerably earlier than that of Jenner's experiments with inoculation. For nearly twenty years, Jenner made observations and experiments, until in May, 1796, he vaccinated a boy of eight with lymph taken from cowpox pustules on the hand of a milkmaid. Shortly after this the boy was inoculated with some pustules of smallpox and failed to take the disease. This discovery resulted in making possible the conquest of smallpox. The present method of preparing vaccine virus is painstakingly safeguarded. Healthy calves, preferably from six months to two years old, are kept under sanitary conditions until it is certain that they have no disease. They are then inoculated with smallpox virus on carefully sterilized areas on the ventral side of the body. Later these areas become covered with small vesicles which contain the smallpox virus. This virus is then collected, placed in sterile containers, treated with glycerol and distilled water, and allowed to stand three to four weeks. It is then ground up and put into small containers for use by physicians. Every step in the process is carefully protected, so that if fresh virus is used there is absolutely no danger to the

patient in vaccination, and almost certain immunity against smallpox is conferred.

Nevertheless, smallpox is still with us. Frequent outbreaks still occur and it is much to our shame that the United States has one fifth of all the smallpox in the civilized world. During the years 1921-1926 Massachusetts, with a population of 4,197,000, had 64 cases of smallpox, though only 2 deaths, while California, with a population of 400,000 less, had 26,985 cases and 392 deaths. This difference in smallpox rate was not due to climate or conditions of inhabitants,



Deaths from smallpox occur almost entirely in states that do not enforce compulsory vaccination laws.

but simply to the fact that in 1911, laws compelling vaccination as a prerequisite for school attendance in California were repealed and in 1921 all compulsory vaccination laws were repealed, while in Massachusetts, vaccination is compulsory. In areas where vaccination is required the rate of smallpox is almost zero.

In the case of typhoid we have a nearly conquered enemy. Primarily a disease of the digestive tract, the bacilli enter the body with raw foods and leave the body in the feces. Hence, any food or drink that is contaminated with sewage becomes a potential source of infection. Prior to 1890, the death rate from typhoid was frequently as high as 200 per 100,000 inhabitants, while today in the country at large the death rate from typhoid and paratyphoid is only a little over 3 per 100,000. This change has been brought about first through the knowledge that epidemics are usually due to contaminated water or milk. Filtration plus chlorination of water supplies has cut out the offending bacillus from water. Pasteurization of milk has almost eliminated this source of danger, although there are still epidemics which are due to poor milk supplies. As late as 1927 Montreal, Canada, had an epidemic of 4755 cases of typhoid which were distributed through milk. A report of the epidemic says that "surface streams were commonly used as sources of water for the milk houses (houses where the milk was prepared for shipment) and for the dis-

posal of sewage from the homes up stream," and in one milk-receiving station "the water used mainly for washing the cooling vats and other equipment was pumped from the river."

Bacterins and Their Use

Typhoid fever has been largely brought under control by means of a vaccine known as a *bacterin* because it is made from dead causative bacteria. The principle underlying vaccination is that the body works up an active immunity by the introduction of large numbers of dead typhoid germs. The presence of the dead bacilli stimulates certain living cells in the body to make antibodies, thus causing the body to acquire immunity. The immunity acquired probably does not last more than two or three years, so that typhoid inoculation should be given within this period if continued immunity is to be expected. Bacterins are now used as protective agencies against cholera and plague. During the World War a mixture of four vaccines (typhoid bacilli, paratyphoid bacilli A and B, and cholera spirilla) was used successfully by Castellani in Serbia to control these diseases. A vaccine made of living bovine bacilli cultivated in the laboratory long enough to make them lose their virulence is the basis of the Calmette vaccine which is used as a preventive against tuberculosis. There seems to be divided opinion as to the value of this treatment.

The Menace of the Carrier

Although we can protect our milk and water supplies and to a very large degree control typhoid through the use of cooked rather than raw foods, we cannot protect ourselves adequately from the one menace that keeps typhoid and certain other intestinal diseases constantly with us. People recovering from typhoid frequently carry bacteria in the body for some time after the disease. Such people are called temporary carriers. Frequently the germs are carried for longer periods, the person being apparently well. People have been found to be carriers when no typhoid history can be traced. Such a chronic carrier was the cook known as "Typhoid Mary." Presumably the typhoid bacilli were transferred to food by means of her dirty hands. During a period of fourteen years she was responsible for forty-nine cases of typhoid. The typhoid carrier is more common than is usually realized, and since isolating carriers is a form

of attacking personal liberty, a serious legal problem is involved in their control.

In order to stamp out parasitic diseases absolutely, there must be effective control of the activities of carriers. This is a difficult matter to carry out because of the injustice worked on the carrier who frequently must make a living. Perhaps medical discoveries will find some way to make carriers safe, but at least they must be educated as to their potential danger to others. Upon their co-operation, the health of a community frequently depends.

Vaccines and Attenuated Organisms

The story of the use of vaccines in the fight against germ disease is tied up closely with the work of Louis Pasteur. In 1880, while he was engaged in an investigation of chicken cholera, several virulent cultures of cholera bacteria were overlooked and left in the laboratory. Some days later these organisms were used to inoculate healthy fowls. To Pasteur's surprise the birds did not die and later were found to be immune to the deadly chicken cholera germs. This discovery gave Pasteur the idea of using weakened or attenuated cultures of bacteria in inoculation as a protection against disease. Continued study showed that anthrax, if grown in the laboratory at a relatively high temperature, was also much weakened and could be used successfully in inoculation against anthrax in sheep and cattle.

The same idea was used in Pasteur's famous and successful attack on rabies. It is a dramatic episode worth the telling. Rabies, a disease of dogs transmissible to man, had long been known as a dread and incurable enemy of mankind. Pasteur first unsuccessfully tried to make vaccine from the saliva of rabid dogs, but later found that, since the disease attacks the central nervous system, the dried nerve-cord of infected animals gave him a source for the inoculating virus. He dried nerve cords of infected rabbits for a period of fourteen days and found that by that time the organism had lost its virulence so that, when inoculated into dogs, it had no effect. Beginning with cords dried for thirteen days and continuing inoculations made from crushed fragments of cords which had only dried one day, Pasteur was able to prove that dogs bitten by other rabid dogs were protected against the disease. But to carry this experiment over to human beings was another matter. Ultimately a small boy from the province of Alsace, terribly lacerated by a mad dog, was brought to his laboratory. It was a life or death case and Pasteur made the inoculations with fear and

misgivings. The treatment proved successful and the praise of Pasteur was sung all over the world. One more disease had been conquered through the use of vaccines. In this particular case, the causal agent has never actually been found, but it is thought to be a filtrable virus, which once within the body attacks the central nervous system.

Rabies has been dreaded most, not because of its prevalence, but because of its deadly nature. In well-developed cases recovery is very rare, the mortality being practically 100 per cent. In 1886, when treatments at the Pasteur Institute were first being undertaken on a large scale, 2671 persons were treated with a mortality of less than 1 per cent. By 1912 the mortality was reduced to 0, showing the efficacy of this treatment.

Hay Fever

Still another type of disease is fought by means of the principle of active immunity. Sufferers from hay fever and from hay fever hives and certain forms of food poisoning are found to be susceptible to certain proteins. These may be in the form of pollens in the case of hay fever sufferers, or in the form of certain types of foods, or other proteins, such as hair, feathers, and even dust, in the case of asthma or food-poisoning symptoms. In order to discover what causes the susceptibility, extracts of different pollens or different food substances are placed on small abrasions in the skin. An almost immediate reddening welt is formed if the patient is susceptible to the substances. Much relief is afforded and sometimes a total cure of these symptoms is found in an *antigen* manufactured from the offending proteins which is inoculated in gradually increasing doses until the body builds up resistance sufficient to give tolerance to the offending substance.

Passive Acquired Immunity

Another type of immunity depends not on the use of bacteria, but instead, on their products or toxins. Such antitoxin treatment consists of neutralizing the toxin given off by bacteria in the body with immune bodies which have been developed by other organisms. The use of antitoxin is associated with diphtheria, since it was in connection with this disease that this method of treatment was first worked out.

In 1888, Roux, working in Pasteur's laboratory, found that the diphtheria germ produces a toxin which causes the symptoms of the disease, and a little later the German, von Bering, found that a serum made from the blood of animals that had been made immune

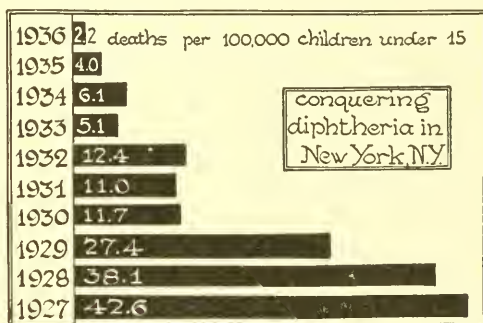
to diphtheria could, when inoculated into other animals, confer this immunity upon them. A protective antitoxin was first used in 1893 in Berlin and a perfected antitoxin made from the blood of the horse was used with startling success in this country in 1895. In 1916, a modified treatment in which the toxin of the germ was injected along with the antitoxin resulted in a better protection because the natural defenses of the body were stimulated by the small amount of toxin injected to form antibodies, while the antitoxins protected the body from harmful effects. This *toxin-antitoxin* treatment was in turn improved upon in 1923 by two workers, one in France and the other in England, who found that diphtheria toxin treated with formalin lost its toxic power but at the same time continued to produce immunity. This substance, called a *toxoid*, bids fair to become the only method used. It will be noted that this is an *active* immunity and not passive such as that produced by antitoxin.

Another control measure against diphtheria has been found in the so-called Schick test, named after its discoverer, Bela Schick. This test shows immediately

whether a person is susceptible or immune to the disease. A very minute amount of diphtheria toxin is injected into the outer skin and if the person is susceptible, an almost immediate reddening of the skin takes place. In 1926, a five-year program to eliminate diphtheria was tried in New York State

in which several agencies co-operated. In general, the program consisted of Schick testing all young children, the susceptible children being immediately treated with toxin-antitoxin. That this program was not completely successful was due to the fact that some people avoided their responsibility. It would be possible to wipe out diphtheria by very early treatment of all babies with toxoid.

Another disease of children which has been responsible for a large number of deaths and much unnecessary illness is scarlet fever. In this disease a new test devised by Dr. and Mrs. Dick and known as the Dick test is used in the same way as the Schick test. A dilute toxin



Education of all parents plus the findings of medical science will ultimately stamp out diphtheria.

produced by the bacteria which causes scarlet fever when injected into the arm indicates susceptibility by a slight swelling and redness of the area. If the scarlet fever toxin is inoculated, the body will work up an immunity against the disease. Another treatment consists in using an antitoxic serum which combats the toxins of scarlet fever in the same way as the diphtheria antitoxin combats the similar diphtheria toxin. Still another child's disease which is now fought by means of passive immunity is measles, where a serum obtained from convalescent measles patients is used as an antitoxic measure.

Other antitoxins are used against tetanus, a much dreaded infection. During the World War soil-infected wounds were immediately treated with this antitoxin and with another worked up against gas gangrene. In consequence the mortality from these infections was much reduced. Antitoxins are also used against certain snake venoms, the mechanism of immunity being apparently the same in poisoning from snake venom as in toxic poisoning from bacteria or other organisms.

Are Parasitic Diseases Conquerable?

In answer to this question, one has only to look at statistics showing the lengthening life span. Certain diseases are nearly conquered. Smallpox, diphtheria, typhoid, yellow fever, and rabies are all almost in sight of the time when they will be under absolute control. Some diseases are more difficult of conquest but are rapidly coming under control, for example, children's diseases such as measles, whooping cough, and scarlet fever, all of which are being attacked through immune sera or vaccines. The difficulty here is that because of the length of the incubation period, children often infect others when their parents do not actually know that they have a given disease. Malaria, tuberculosis, and hookworm are also rapidly coming under control, due to the application of recent discoveries. Certain of our parasitic enemies still remain unconquered. Pneumonia and influenza are among the greatest causes of death when they go on epidemic rampages. The common cold still remains an unconquered enemy both because of its insidiousness and because people do not consider it serious enough to treat as a real disease. Infantile paralysis, meningitis, and many tropical diseases are also as yet uncontrolled. The two venereal diseases, gonorrhea and syphilis, are much more serious enemies than is realized, not only because they are difficult to control but also because of the intimate nature

of the diseases and the social stigma connected with them. Many women, particularly, suffer for considerable periods of time before they understand the nature of the affection. These social diseases deserve much more serious consideration than is given them.

Undoubtedly science will eventually be able to conquer all parasitic diseases theoretically because it is worth while to do so, but such diseases can never be entirely eliminated until Mr. Everyman is willing to bear his share of the responsibility. Not only must he be educated as to methods of control, but he must also be unselfish enough to abide by quarantine laws and regulations, enforcing them himself, and seeing that others also keep them. The reasons for quarantine are obvious when one remembers that the incubation period of a disease, especially children's diseases, is the most effective time for passing on the disease to others. Children coming down with serious diseases often apparently have a slight cold in the head, the nose runs, they cough, and perhaps have a little fever. During such a period the germs can most readily be passed to others, hence the reason for protection during this time as well as later on. Without quarantine the control of infectious diseases is impossible, since a leakage of disease germs through unwillingness to co-operate with authorities means disaster and epidemic.

There must also be a wider knowledge about diseases and control measures on the part of the average voter and citizen. There is need for Mr. Everyman to know how to spend the money which goes into taxes. Less than $2\frac{1}{2}$ per cent of the total expenditures of 253 cities in the United States was used for "conservation of health" in 1921. The picture would not be very different today. In 1923-1924, \$100,000,000 of the Federal budget was appropriated for rural post roads and \$50,000 for rural health work. A survey of American cities made in 1923 showed the average distribution for health work at \$0.71 per capita out of a total per capita expenditure of \$25.09. Figures today would be slightly higher, but the proportion would not differ greatly. While communicable disease may not be controlled by departments of health or even by a well-trained medical profession, it can be stamped out through the use of these agencies plus intelligent action on the part of taxpayers through individual co-operation and understanding. It should be the place of the college trained men and women who read these pages to assume their responsibility in making the world safer from the attacks of communicable disease.

SUGGESTED READINGS

Broadhurst, Jean, *How We Resist Disease*, J. B. Lippincott Co., 1923.

The best book of its kind, although now not up to date. Interesting and authentic as far as it goes.

Dublin, L. I., *Health and Wealth*, Harper & Bros., 1928.

A comprehensive discussion of economic factors as related to health.

De Kruif, Paul, *Microbe Hunters*, Harcourt, Brace & Co., 1926.

The first, and still among the best, of many popular books on the conquering of parasitic diseases.

Downing, E. F., *Science in the Service of Health*, Longmans, Green & Co., 1930.

An elementary but interesting account of the conquest of parasitic disease by men who gave their all for science.

Haggard, H. W., *What You Should Know about Health and Disease*, Harper & Bros., 1928.

General, but interesting and authentic.

Moore, H. H., *Public Health in the United States*, Harper & Bros., 1923.

Valuable for statistical information up to date of publishing.

Park, W. H., and Williams, A. W., *Who's Who among the Microbes*, Century Co., 1929.

Practical applications pertaining to public health and preventive medicine which have been made from the study of bacteria.

Roddie, L. H., *Edward Jenner and the Discovery of Smallpox Vaccination*, George Banta Publishing Co., 1930.

Interesting account of the man and his work.

Smith, Theobald, *Parasitism and Disease*, Princeton University Press, 1934.

One of the latest and best books on the subject by one who has done his part in conquering parasites.

Tobey, J. A., *Riders of the Plagues*, Charles Scribner's Sons, 1930.

An interesting history of outbreaks of parasitic diseases from the time of the Crusades to the present.

Vallery-Radot, R., *The Life of Pasteur*, Doubleday, Doran & Co., 1926. (Garden City Pub. Co., 1926.)

A classic (translated).

THE NEXT MILLION YEARS

PREVIEW. The period of man · Human betterment · Difficulties in any eugenic program · Biological background of eugenics · The moral at the end of the tale · Suggested readings.

PREVIEW

The predictions in this chapter apply only to the next million years. Beyond that time we do not venture to go, nor are we here concerned with the possible future events of the next few years which may fall within the span of our own lifetime, wherein we may be shown to be mistaken in our owlish prognostications. Somewhere between the immediate unfolding future and a million years hence there lies an immense territory of safety for the would-be-wise prophet over which the speculative imagination may freely roam unchallenged.

In any case much is bound to happen in this vast coming time, since the laws of inevitable change are shown to be continuous and unchangeable. They have been in operation upon this planet for so many million years, and have always resulted apparently in so consistent a swing of events, that whatever is likely to occur in the next million years is in a general way reasonably predictable.

The probable advent of mankind in the Pleistocene period some 500,000 years ago forms a comparatively recent episode biologically in the grand drama of life, although since *Pithecanthropus*' day the human pattern has been repeated and modified by probably over 20,000 successive generations. When we venture still farther back into the evolutionary past and remember, for instance, that our remote amphibian ancestors were able to pave the way for the development of an animal with a human brain, what unthinkable changes may we not expect to arise in the next comparatively short million years from mankind, with his unfathomable potentialities as a starting point!

The Period of Man

In this changing world during recent geological years, man has been coming more and more into his own. Some of the ways in which

this has taken place are set forth in the unit on "Man's Conquest of Nature," and certain of the possibilities of future human control of the environment are pointed out in other units.

There is no doubt that modern science in the hands of intelligent man has become a magic key admitting him to castles of mystery and delight, as well as opening to him storehouses of energy by means of which he will be able still further to control and transform the world.

The invention of labor-saving devices and the dawn of the Machine Age have liberated mankind from much of the time-consuming drudgery which forms an inevitable part of daily living, and have provided him with a larger leisure for intellectual adventure and a more abundant life. It is not enough, however, to secure leisure. The important thing is what will be done with it when it is gained. If it simply turns out that with increasing leisure "Satan finds something for idle hands to do," then, in a very literal sense, there will be the devil to pay in the future. The most important question relating to the future of mankind on the earth is not what kind of world will our descendants find to live in, but *what kind of individuals will they be?*

Human Betterment

Biological, as contrasted with social, control of the potent stream of humanity is the field of EUGENICS. As an organized science it is still in its swaddling clothes, although as an art it has been practiced more or less blindly ever since there have been animals that were human. W. H. P. Faunce once said, "To neglect eugenics today is to neglect the whole future of humanity and to insure catastrophe."

One reason why the fallow field of human heredity has not attracted the scientific husbandman earlier is that its rewards are mostly projected so far into the future. Why labor to plant slow-growing seedlings of forest trees which promise scanty or no returns until after one is dead and gone, when one can sow a field of wheat with the prospect of an early harvest? It is difficult to visualize and to become enthusiastic, or even academically interested, in remote great-great-great-great-grandchildren whom we can never know, when there is so much of immediate pressing concern presented to us by contemporaries whom we can daily see about us.

Obviously there are two outstanding ways by which to contribute towards a better future world for our followers to live in on this earth. One way is that of EUTHENICS, that is, by the modification and

amelioration of the environment. It involves the accumulation and transfer of material things, such as property and possessions of all sorts, inventions and the triumphs of applied science, traditions and literatures, in short, everything that contributes to a better stage setting. This method, however, is uncertain and transitory. The frequent failure of legally drawn wills, designed to secure financial and social security for following generations, illustrates how the grasp of the dead man's fingers may weaken and relax. In a larger way the perspective of history shows repeatedly how different civilizations in the past have been replaced or dissipated, and there is reason to believe that no civilization possesses the germs of permanence. The flowers of the environment fade, but meanwhile the seeds of heredity live on and furnish the essential living source from which renewal is possible.

The other way of providing for human betterment is by **EUGENICS**, which has been defined as "race betterment through good ancestry." It provides better actors to utilize the stage setting.

Whether we consciously direct the stream of human germplasm or not, it is bound in the long run to be the most fundamental and important of all the factors destined to mold the world of the future. In providing for any Utopia, the program of euthenics is designed to keep humanity out of hell, while the purpose of eugenics is to keep hell out of humanity. Both objectives are desirable.

In cultivating the human garden it is to be noted that less advancement has been made than in the cultivation of animals and plants, due to the peculiar difficulties encountered. William Penn is credited with the gently sarcastic comment, "Men are more commonly careful of the breed of their horses and dogs than of their children."

Difficulties in Any Eugenic Program

The reason for the obvious lag in the development of eugenics, or human genetics, is to a large extent due to the peculiar difficulties encountered.

Owing to the long lapse of time between the generations of mankind, and the comparatively few children produced in each family, it is not practical, even if it were socially permissible, to set up experiments in human breeding in order to establish or to disprove theories of inheritance. Life is not long enough to arrive at satisfactory conclusions from controlled breeding experimentation with man. Consequently, the data about the heredity of man must come largely

from uncontrolled experiments in human matings already performed. The evaluation of such data can be adequately handled only by means of the elusive and illusive technique of statistical treatment. Moreover, the collection of facts about human beings is inevitably colored and distorted by pride and prejudice. Plants and animals do not tell lies about themselves, but some human beings do.

The fact that here one more often deals with complex *traits* rather than more directly with the elementary *genes*, and that the smoke screen of training and education plays, in man, a particularly confusing rôle by covering up the contrasting effects of heredity and environment, makes the analysis of the human hereditary picture all the more difficult.

While there is no doubt that the fundamental laws of Mendelism, which go so far to elucidate hereditary procedure in plants and animals generally, are equally applicable to mankind, they cannot be subjected to the same demonstrable proof. Even the most ardent disciple of eugenics would hesitate to propose the back-cross of a man with his recessive grandmother in order to determine his genetic constitution.

The fact that a problem is difficult, however, does not mean that it cannot be solved. The more difficult it is the greater the challenge presented and the greater the final satisfaction when a successful solution is eventually found.

Biological Background of Eugenics

In spite of obvious difficulties, a workable program of eugenics is by no means a hopeless proposition, since biological science has already furnished much solid ground for eugenics to stand upon. It is quite definitely established, for example, that biological inheritance in man, as in other organisms, depends primarily upon *continuity of the germplasm* rather than upon somatic contributions acquired during the lifetime of the parents, and that consequently any characteristic which an individual possesses arises not *from*, but *through*, the bodies of the parents from more remote ancestral sources. The parents, therefore, are to be regarded not as the *source* of the child's heredity, but simply as the trustees and guardians of the hereditary stream whose springs lie far back in the cloud-covered mountains of the evolutionary past.

Mendel has shown us how purity can arise from impurity, not by any miraculous process of the "forgiveness of sins," but by the

segregation of genes. He also makes plain why too close inbreeding, among those strains that possess too many hidden "skeletons in the closet," is hazardous. Relatives are apt to carry the *same kinds of undesirable recessive characteristics*, which thus have a sporting Mendelian chance of joining hands and becoming evident whenever cousins marry. On the other hand, recessive traits, desirable or undesirable, may be carried on for an unlimited number of generations hidden under the shadow of corresponding dominant traits contributed through the other parent.

This leads to the practical idea that the way to discover the genetic potentialities of any individual is not simply to take account of the characteristics which the person in question presents, but to observe what shows up among the immediate relatives, who are presumably exploiting the same general mixture of germplasm. The mother-in-law joke is *no* joke. Every man in a eugenical sense marries all his wife's relatives.

Finally, one of the most significant contributions of biological science to eugenics, which is often not appreciated even by those who have heard about it, is the well-established fact of the peculiar behavior of the germ cells before their union to form a new individual, whereby half of the hereditary potentialities carried by each parent is irretrievably lost. The consequence is that the *amount inherited from any particular ancestor* is not dependent upon the number of generations that ancestor is removed, but upon the devious fortunes of chance assortment and elimination of the genes during the preparation of the eggs and the sperm for their union.

The Moral at the End of the Tale

We cannot change our individual biological inheritance. That was determined for us once and for all and entirely without our connivance at the time when the egg from which we developed was fertilized. The cards were then dealt and all that we can do now is to play out the hand. Fortunately this may be done in a variety of ways, a fact that makes every individual life worth living.

"I am the legatee of fierce desires,
A strange bequest of sundry hopes and fears,
Loves, hates, and hidden smouldering fires,
Has come to me unsought far down the years

From whose name I bear; themselves the heirs
 Of time, and race, through every bygone age
 Of man. And I am not myself, but theirs
 Who so devised this jumbled heritage.

"Yet I thank God, and thank Him with a song,
 That He gave me a will that is my own,
 And made me free to choose the right and wrong,
 And fight and fashion life as I shall choose.
 And with this gift I sigh for no man's shoes,
 Nor envy any king upon his throne.
 So fare I forth intent at least to be
 Master, not slave, of my strange legacy."¹

Finally, the possibility of *eugenic control*, or changing the hereditary stream, arises *only when a mate is chosen* with whose germplasm our own may be combined. This is shuffling the cards and dealing a new hand. It is the task of eugenics to see that it is intelligently done.

"Eugenics indicates a new method of striving for human welfare which, if combined with an equal striving for improvements in human surroundings, more truly justifies a hopeful outlook than any other which has yet been tried in the whole history of the world."²

The prospect for the next million years would be bright indeed if everyone heeded the *eugenic golden rule*, that is, DO UNTO YOUR DESCENDANTS AS YOU WOULD HAVE HAD YOUR ANCESTORS DO UNTO YOU.

SUGGESTED READINGS

Darwin, L., *What Is Eugenics?* Galton Pub. Co., 1929.

A popular exposition by the Honorary President of the International Federation of Eugenic Organizations.

Holmes, S. J., *Human Genetics and Its Social Import*, McGraw-Hill Book Co., 1936.

The newest of several books this biologist has written upon eugenics.

Huntington, E., *Tomorrow's Children*, John Wiley & Sons, 1935.

Questions and answers concerning eugenics.

¹ William Woodford Rock in the *Christian Century*, May 7, 1925. By permission of the publishers.

² From Leonard Darwin, *Eugenic Reform*. By permission of D. Appleton & Company, publishers.

Popenoe, P., and Johnson, R. H., *Applied Eugenics*, The Macmillan Co., 1933.

Particular attention to social aspects.

White, F. W., *Posterity*, Galton Pub. Co., 1930.

A small book of sane propaganda from England.

Wiggam, A. E., *The Next Age of Man*, Blue Ribbon Books, 1931.

Easy and worth while to read.

Eugenics Record Office, Cold Spring Harbor, Long Island, N. Y.

Headquarters for information of all sorts about eugenics.

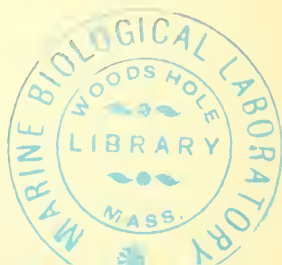
INDEX

Italicized numbers indicate illustrations.

- Aardvark, 508
- Abiogenesis, 408
- Abomasum, 288
- Absorption, by root hairs, 244-245
- Absorption spectra of green plants, 257
- Acanthocephala, 87
- Achatinella, 523
- Acid-base balance, 310
- Adaptability, to new conditions, 40
- Adaptations, 486-493
 - biological, 492-493
 - embryological, 487-488
 - for food getting in animals, 51-52
 - for food getting in birds, 52
 - for life in air, 23-24
 - for life in water, 21-22
 - for life on land, 24-25
 - for protection of young, 47
 - for seed dispersal, 272
 - genetical, 489-490
 - in desert plants, 36, 37
 - in worker bees, 207-208
 - organic, 486
 - physical, 490-492
 - physiological, 488-489
 - psychological, 489
 - structural, 486-487
- Adaptiveness, definition of, 127
- Addison, 391
- Addison's disease, 393
- Adenoids, 287
- Adjustor neuron, 341
- Adrenals, 392-394
- Adrenin, 393, 394
- Adrenotropic hormone, 401
- Aedes mosquito, 618, 619
- Aepyornithiformes, 113
- Aerating devices, in plant, 17
- Aestivation, 10
- Afferent fibers, in bee, 211
 - in earthworm, 194, 195
- Agassiz, 502
- Ages, cultural, 547
- Agglutination test for typhoid, 627
- Agglutinins, 626
- Agnatha, 105
- Agouti, 508
- Agriculture, 550
- Ainu aborigines, 561
- Air sacs, 315
 - function of, 210
 - in insects, 210
- Alare, 563
- Albatross, 113, 523
- Algae, 69, 71, 169-172
- Alimentary canal, 282
- Allantois, 426, 427, 487, 501
- Alligators, 103, 111
- Alpine races, 561
- Alternation of generations, 414
 - angiosperms, 176-178
 - hydroids, 186
 - plants, 174-176, 175
- Alveolus, 317
- Ambulacral fluid, 335
- Ambulacral grooves, 336
- Ameba, 77, 103, 328, 342
 - food of, 155
 - mitotic division in, 155
 - structure of, 154-156
- Ameba proteus, 154
- Amebic dysentery, 620
- American Ornithologists' Union, 600
- American passenger pigeon, 599
- Amino acids, definition of, 131
- Ammonites, 513
- Amnion, 424, 425, 427, 487, 497
- Amniotic fluid, 426
- Amphibia, 103, 109, 497, 501, 513, 533
- Amphimixis, 161, 162, 163
- Amphineura, 97
- Amphioxus, 105, 329
- Amphioxus ova, 418
- Ampulla, echinoderms, 336
 - mammalian ear, 361
- Amylopsin, 295
- Anabolism, 126
- Analogy, 67
- Anal spot of Paramecium, 159
- Anaphase, 142, 143
- Anatomy, comparative, 496-497
 - human, 496
- Ancyrocephalus, 223
- Angiospermae, 75
- Angiosperms, alternation of generation
 - in, 176-178
- Animal breeding, methods of, 571-573
- Animal cell, typical, 130
- Animals
 - as food, 575
 - economic value of, 576-578
 - harm done by, 582-586
 - in fresh water, 153-154

- Annelida, 93, 103, 344
 Annual rings, 246, 247
 Annuals, 240
 Anodonta, 97
 Anopheles mosquito, 618
 Anoplura, 101
 Anseriformes, 114
 Ant-eater, 487
 Antelopes, 509
 Antennae cleaner, 207
 Antennae, insects, 199, 202, 205
 Anterior limb, 332
 Anterior peduncles, 351
 Antheridia, moss, 175
 Oedogonium, 172
 Anthozoa, 81
 Anthrax, 622
 Anthropological measurements, 563
 Anthropology, 531
 Anthropometry, 563
 Antibodies, 218, 303, 311, 514
 Anticoagulin, 217
 Antienzyme, 217
 Antigen, 632
 Antitoxin, diphtheria, 632
 Antitoxins, 489
 Ants, 549
 Anura, 109
 Aorta, 309
 Aortic arches, 308, 309
 Aortic plexuses, 354
 Ape-man, 565
 Apes, 115, 233, 514, 535, 538, 539,
 544, 551
 experiments with, 386-387
 Aphids, 413
 Apical nervous system, 343
 Apoda, 109
 Appendages, 329
 Appendix, 292
 Apterygiformes, 113
 Aqueduct, 350
 Aqueous humor, 360
 Arabs, 561
 Arachnoidea, 102
 Arachnoid membrane, 345
 Arbacia, 95
 Arbor vitae, 350
 Arcella, 77
 Arcellidae, 328
 Archaeopteryx, 113, 506, 507
 Archaeornithes, 113
 Archegonia, moss, 175, 176
 Archenteron, 418
 Archeozoic era, 475, 476, 513
 Archiannelida, 93
 Arctic tern, migration of, 38
 Aristotle, 437
 Armadillo, 115, 508
 Armbruster, L., 208
 Armenians, 561
 Armenoid races, 561
 Armor, protective, 493
 Arms, evolution of, 544
 Arteries, 304, 305
 Arthropoda, 67, 68, 99, 103, 328, 334,
 336, 344
 structure of, 199
 Arthropods, 234
 parasitic, 222
 Artifacts, 479, 554
 Artificial light, relation to food-making
 in green plants, 259-260
 Artiodactyla, 117
 Ascaris, 423
 infection by, 617
 Ascaris lumbricoides, 225
 Ascaris megaloccephala bivalvens, 428
 Ascidians, 105
 Ascomycetes, 71, 73
 Asexual development, in Hydra, 184
 Asexual propagation, 455
 Asexual reproduction, types of, 410-
 411
 Ash, plant residue, 242, 254
 Associations
 plant and animal, 5-20
 maple-birch, 28
 Asteroidea, 95
 Asthma, 394
 Astrangia, 81
 Astronomy, 473
 Atwater, 276, 312
 Aucter, E. C., 249
 Auditory nerve, 352, 361
 Augustine, Saint, 494
 Aurelia, 81
 Auricle, 308
 Aurignacians, 557, 560
 Autonomic nervous system, 354, 355
 Autosomes, 469
 Autotomy, 410
 Aves, 103, 113
 Axial filament, sperm, 415, 416
 Axial gradient theory, 365, 381, 431
 Axon, 340, 359
 Azeel fowl, 515
 Aztecs, 562
 Baboon, 508, 537
 Bacillus, 71, 165
 Backbone, curvature of, 542
 Bacteria, 69, 71, 216
 aerobic, 59
 anaerobic, 59
 ecological adaptations in, 490
 forms of, 165
 how they enter the body, 622

- life habits of, 59
- relation to disease, 621
- relation to free nitrogen, 59-60
- spores of, 166
- structure of, 165-166
- Bacterial infections of plants, 579
- Bacteriins and their use, 630
- Bacteriophage, 627
- Bacterium, 71
- Baird, 7
- Balancing organ, crustacean, 372
- Balanoglossus, 105
- Balanus, 500
- Balkans, 561
- Banting, 296, 397
- Bark, 247, 248
- Barnacles, 99, 500
- Barrell, estimate of geological time by, 553, 554
- Barriers
 - biological, 32, 533
 - chemico-physical, 30
 - geographical, 31, 523
 - mountain, 30
- Basic environments, 7
- Basidiomycetes, 73
- Bateson, experiments of with sweet peas, 451
- Bats, 115, 534
 - specialization of wing, 544
- Bauhin, Kasper, 64
- Bayliss, 392
- "Beagle," voyage of, 508, 518
- Bean, Professor
 - estimate of age of flints by, 547
 - estimate of geological time by, 553
- Bears, 385, 509
- Bee
 - head of worker, 204
 - mouth parts, 203-205
- Beebe, William, 22, 27
- Beetles, 101
- Bergson, theory of evolution of, 527
- Behavior, definition of, 366
- Behavior patterns, 381-382
- Behaviors, as adaptive responses, 380-381
- Belly, of muscle, 338
- Benedict, 312
- Berbers, 561
- Bering Sea, 511
- Bering Strait, 509
- Bernard, Claude, 391
- Berthold, A. A., 391
- Best, 296, 397
- Biceps, 338
- Biennials, 240
- Bilateral symmetry, evolution of, 532
- Bile, 296
- Binary fission, 411
 - Ameba, 155
 - Paramecium, 160
- Binomial nomenclature, 63, 64, 65
- Biogenetic Law, 501
- Biological surveys, 603
- Biometry, 440
- Birds, 103, 113
 - economic value of, 577-578
 - embryological adaptations in, 487
 - evolution in, 532
 - hearts of, 497
 - in mesozoic era, 452
 - in recapitulation theory, 501
 - insect eating, 578
 - physical adaptations in, 491
 - relation of blood to other animals, 514
 - rise of in evolution, 513
 - seed-eating, 578
 - sex inheritance in, 468
 - species of lice on, 524
- Bison
 - distribution of, 509
 - La Brea fossils of, 477
- Blackberry, white, 455
- Black stem grain rust, 57
- Bladderwort, leaf of, 54
- Blastocoel, 418
- Blastoderm, 417
- Blastomeres, 432
- Blastopore, 420
- Blastostyle, Obelia, 186
- Blastula, 418
 - earthworm, 197
- Blastulation, 418
- Blind spot, 359
- Blood
 - earthworm, 191-192
 - insects, 210
 - transportation of in vertebrates, 233
- Blood platelets, 302-303
- Blood sinuses, bee, 209
- Blood sugar raising principle, 401
- Blood vessels, earthworm, 190-191
- Body cavity, 426
- Body parts, insect, 200
- Body surface, respiration, 314
- Body wall, insect, 202-203
- Bolus, 290
- Bombinator (toad), biological adaptations in, 492-493
- Bones, ankle, 332
 - cartilaginous, 329
 - cranial, 330
 - facial, 330
 - membrane, 329
 - metacarpal, 332
 - metatarsal, 332



- Bones (cont.)
 occipital, 329, 330
 skull, 329, 330
 wrist, 332
 Bony fishes, 107
 Boöphilus annulatus, 216
 Bose, J. C., 371
 Botany, systematic, 64
 Botflies, 216
 Boule, estimate of geological time by, 553
 Bowman's capsule, 323, 324
 Boyle, Robert, 528
 Brachiopoda, 91, 328
 Brachiopods, 485
 rise of, 513
 Brain, 329, 344
 anatomy and development of, 345-352
 human, 544, 545, 551
 parts of the vertebrate, 347
 Branchiostegite, 315
 Breastbone, 331
 Breeding, practical, 452-454
 Bretz, estimate of geological time by, 553
 Brittle-stars, 328
 Broad tapeworm, distribution of, 614
 Bronchioles, 317
 Bronchus, 317
 Bronze age, 547
 Broomrape, 216
 Brown-Sequard, 391
 Brues, work of, on physical adaptations, 490-491
 Bryophyta, 73
 Bryozoa, 91
 Bryozoans, 491
 Bubonic plague, 222, 620-621
 Buccopharyngeal respiration, 314
 Budding, 410
 Bugula, 91
 Bullfrog, 490
 Bulls, pedigree breeding with, 453
 Bumpus, report of on survival in sparrows, 520
 Burbank, plant breeding of, 455
 Busycon, 97
 Buttel-Reepen, estimate of geological time by, 553
 Butterflies, sex heredity in, 468
 Cacti, biological adaptations in, 493
 Cactus, spineless, 455
 Caeca, 283
 Caecilia, 109
 Caecilians, 499
 Calcaneus, 543
 Calcarea, 79
 Calciferous glands, earthworm, 189
 Calcium, 277
 Calorimeter, bomb, 276
 Calyces, 323
 Cambium, 245, 246, 248
 Cambrian period, 476, 513
 Camel, evolution of, 509
 Camera eye, 358
 Camouflage, a biological adaptation, 492
 Cancer, 612
 Canines, 286
 Cannibalism, animal, 49
 Capillaries, 304, 305, 309
 lymph, 304
 Capillary tube, 268
 Capsule, moss, 176
 Capuchins, 536
 Carbohydrates, 276, 277, 298
 Carbon dioxide, 318
 use of in starch-making, 254
 Carboniferous, 476, 513
 Cardiac plexuses, 354
 Cardiac portion of stomach, 288
 Caribou, distribution of, 509
 Carnegie Trust, 516
 Carnivora, 115
 Carnivores, and struggle for existence, 520
 blood relationships in, 514
 structure adaptations in, 487
 teeth of, 52
 Carnivorous plants, 53-54
 Carotin, 258
 Carpal bones, 332
 Carrel, Alexis, 610
 Carriers
 disease, 630-631
 mechanical, 221
 Carrion beetle, 490
 Carrot, 239
 Cartier, Jacques, 570
 Carteria, 69
 Cartilage, 329
 Cassowaries, 113
 Castings, earthworm, 190
 Castle
 definition of gene by, 457
 experiments of with germplasm, 438
 Casts, fossil, 478
 Casuariiformes, 113
 Cat, 495, 499
 Catalyst, 280
 Catherinia, 73
 Cattle, 511, 515
 superior strains of, 573
 Cave-bears, 550, 557
 Cave-dwellers, 492, 500, 552, 557
 Cave-hyena, 550, 557

- Cavity, buccal, 284
 Cell division
 mitotic, 141-144
 theories concerning, 140
 Cell of mesophyll of leaf, 129
 Cell theory, 128, 138, 139
 Cell wall and protoplasm, 134
 Cells
 comparative size of, 140
 tissue, 144-148
 Cement, 287
 Cenozoic era, 476, 512, 513, 553, 554
 Centipedes, 532
 Central nervous system, 337, 420
 early development of, 345, 346
 Centrioles, 416
 Centrosome, 142
 Centrosphere, 142
 Cephalochordata, 105
 Cephalopoda, 97
 Cercariae, 219, 231
 Cerebellum, 346, 350, 353
 Cerebral hemispheres, 346
 Cerebrospinal fluid, 345
 Cerebrum, 346, 347, 353
 human, 545
 Cestoda, 85
 Cestus, 83
 Cetacea, 117
 Chaetognatha, 93
 Chaetonotus, 89
 Chaetopoda, 93
 Chalina, 79
 Chamberlin, 407
 Change, universality of, 483-485
 Chara, 71
 Charadriiformes, 114
 Charophyceae, 71
 Chelonia, 111
 Chemical co-ordination, 391-392
 Chemical relationships of plants and
 animals, 57-59
 Chemistry, food making in green
 plants, 261-262
 Chestnut weevil, 487
 Chick, 500
 Child, 365, 381, 431
 Chimpanzee, 386, 537, 538
 Chin, development of, 551-552
 Chiroptera, 115
 Chitons, 97
 Chlorine, 277
 Chlorogogen cells, earthworm, 189
 Chlorophyceae, 69
 Chlorophyll
 action of in starch making, 258, 262
 and light, 256-258
 chemical composition of, 258, 262
 definition of, 13
 Chloroplasts
 definition of, 129
 effect of light on, 260
 in green leaf, 252, 260
 part played by in heredity, 465
 structure of, 257-258
 Choanoflagellate (collared) cells, 281
 Chordae tendineae, 307, 308
 Chordata, 103, 105
 Chordates, 328
 Chorion, 424, 425
 Chorionic cavity, 426
 Choroid, 359
 Chorology, definition of, 26
 Chromaffin cells, 392
 Chromosome map, 461, 462
 Chromosomes, 456-457
 numbers of, 142
 Chronological age, 388
 Chyme, 294
 Ciconiiformes, 113
 Cilia, 21, 334
 Circulation, 300-310
 bee, 209-210
 earthworm, 190
 Circulatory system, closed, 302
 Circumesophageal connectives, 344
 bee, 211
 earthworm, 194
 Circumesophageal loop, 344
 Cirri, 335
 Civilian Conservation Corps, 594, 595
 Cladocera, 413
 Clams, 97, 103, 235, 328, 333
 Classification, 64-117
 animal, 77-117
 evolutionary evidence from, 504
 plants, 69-77
 Climax formation, definition of, 32
 Clinostomum marginatum, life cycle of,
 230, 232
 Clitellum, earthworm, 188
 Closed fibrovascular bundle, 250
 Closterium, structure of, 164
 Clotting, 311
 Club mosses, 75
 Cnidoblasts, Hydra, 180
 Coal, 479
 Coecus, 165
 Coecyx, evolution of, 543
 Cochlea, 362
 Cockroach, mouth parts of, 487
 Cocoa production, annual, 574
 Codfish, 329
 Coelenterata, 81, 103, 180, 281, 301,
 320, 343, 499, 531
 colonial, 334
 Coelom, earthworm, 188
 Coelomic cavity, 426

- Coffee production, annual, 574
 Cohesion, in rise of water, 269
 Coincidence in chromosomes, 457
 Cold receptors, 363
 Coleoptera, 101
 Collembola, 99
 Collip, 396
 Colloid, definition of, 132
 Colon, 292
 Colonial theory, 139
 Colostrum, 625
 Colymbiformes, 113
 Comatrichia, 71
 Commensalism, 56, 492
 Communicable diseases, spread of, 612
 Comparative anatomy, 330
 evolutionary evidence from, 496
 Competition, relations of, 49-50
 Complex reflexes, 342
 Compound eyes, 358
 Compound reflex arcs, 341
 Condiments, 277
 Conditioned behavior, 379-380
 Conditioned reflex, law of, 380
 Coneys, 117
 Conjugation, 411
 Connecting links in evolution, 506
 Connecting neurons, 376
 Connective tissue, 338
 Connective tissue membrane, 329
 Consciousness, in animals, 383
 Conservation
 lack of unified program in, 605-607
 methods of, 601-602
 of wild life, 600-601
 organizations for, 602-603
 Contractile vacuoles, 320
 Co-ordination by a dorsal tubular nervous system, 344-345
 Co-ordination by a linear nervous system, 344
 Co-ordination by a nerve ring, 343-344
 Co-ordination by a network, 343
 Copper age, 547
 Coprolites, 479
 Copulation, earthworm, 196
 Coracidia, 230
 Coraciiformes, 114
 Corallopsis, 71
 Corals, 81, 103, 328
 rise of, 513
 skeletons of, 478
 Cork cambium, 247
 Corn, linkage and crossing over in, 460
 Corn stem, cross-section of, 249
 Cornea, 359
 Corpora bigemina, 350
 Corpora quadrigemina, 350
 Corpus callosum, 348
 Corpus luteum, 399
 Correns, experiments of in heredity, 443, 446, 467
 Corrodentia, 100
 Cortex, adrenal, 392
 Cortex, cerebral, 348, 545
 Cortex, kidney, 323
 Corti, organ of, 370
 Cortin, 392, 393
 Costal plates, 328
 Cotton boll-weevil, 585-586
 Cousin marriage, 454
 Cows, breeding of, 453
 Coxa, 206, 207
 Crab, horseshoe, 499
 Crabs, 99, 103, 531
 Cranial nerves, 351, 352
 oculomotor (III), 350
 trochlear (IV), 350
 Craniota, 105, 507
 Cranium, 329, 330
 Crayfish, 333
 Creation, miraculous, 493-495
 Creator, 527
 Cretaceous period, 476, 513
 Cretans, 561
 Crinoidea, 95
 Crocodiles, 533
 heart of, 497
 Crocodilia, 111
 Crômagnons, 557, 559, 560
 Crop, 288
 earthworm, 189
 insect, 208
 Crops, rotation of, 60
 Cross-fertilization, 412
 Crossing-over, 458-460
 Crow, 552
 Crown, tooth, 286
 Crura cerebri, 350
 Crustacea, 99, 103, 302
 Crustaceans, 234, 499, 521, 532
 Cryptobranchus, 314
 Crypturiformes, 113
 Crystalloid, definition of, 132
 Ctenophora, 83
 Cuculiformes, 114
 Cutaneous sense organs, 362-363
 Cutin, 264
 Cuttlefishes, 333
 Cuvier, 516, 517
 Cyanophyceae, 69
 Cycles, carbon and oxygen, 58
 Cyclochaeta, 221
 Cyclostomata, 105
 Cynipoidea, 218
 Cypress (bald), 17
 Cysticercus, 226

- Cysts, 422
- Cytology, definition of, 138
- Cytolysis, 136
- Cytoplasm, 416
 - definition of, 129
 - role of in heredity, 463-464
- Czechs, 561
- Dandelion, 505
 - seed dispersion in, 489
- Daphnia, 413, 500
- Darwin, Charles, 443, 488, 493, 495, 508, 513, 516, 518, 519, 522, 523, 524, 526, 527, 528, 530, 540, 555, 556
- Darwin, Erasmus, 494
- Darwin, Leonard, 494, 642
- Datura, 457
- da Vinci, Leonardo, 305
- Death, biological significance of, 610-611
- Deer, 335
- Deficiency, in chromosomes, 457
- Deletion, in chromosomes, 457
- Desmospongia, 79
- Dendrites, 340
- Dengue, 620
- Dentalium, 97, 432
- Denticula, 71
- Dentine, 286
- Dermo-muscular sacs, 335
- Dermoptera, 101, 115
- de Saussure, 241
- Desmids, 164-165
- Determinate cleavage, 432
- Determiners, 450
- Development, 415
- Devonian period, 476, 513
- DeVries, 443, 524, 525
- Dextrin, 295
- Diabetes, 296
- Diaphragm, 318
- Diatoma, 71
- Diatomaceae, 71
- Diatoms, 21, 163-164
 - shells of, 163
 - uses of, 163
- Dicotyledons, 64, 75, 77
 - definition of, 240
- Dick test, 633-634
- Diencephalon, 346, 348, 397, 400
- Differentiation of the embryo, 420-421
- Diffusion, 133-134
- Digestion
 - Ameba, 154-155
 - extracellular, 281-284
 - in higher animals, 282
 - Hydra, 182
 - insects, 209
 - intracellular, 281
 - in lower animals, 281-282
 - Paramecium, 159
- Digestive glands, 282
- Digestive systems (intake devices), 275
- Digestive tract
 - earthworm, 189
 - insect, 209
- Digitigrade feet, 333
- Dihybrids, 447, 448
- Dinornithiformes, 113
- Dinosauria, 111
- Dinosaurs, 236, 479, 481, 513, 542
- Diocious plants, 175
- Diphyllbothrium latum, 229
- Diploblastic organisms, 68, 419
- Diplococcus, 71
- Diploid number, 429
- Dipnoi, 107
- Diptera, 102
- Discomedusae, 320
- Discontinuous variations, 572
- Diseases
 - causes of, 611
 - death rates from, 613
 - degenerative, 612-613
 - relations of environment to, 611-612
- Display of energy, animals, 366
- Distribution, evolutionary evidence from, 508-510
- Divergence theory, 503
- Division of labor
 - Coelenterata, 179
 - Hymenoptera, 214
- Divisions of plants, 65
- Division series, 415
- Diverticula, digestive, 282
- Dodder, 216
- Dogs, 329, 515, 552, 639
- Dolphins, 117
- Domestic animals, 576
- Domestication, 550
 - of plants and animals, 569-571
- Dominance, 447-449
- Dorsal cerebral ganglion, bee, 211
- Dorsal pores, earthworm, 188
- Double fertilization, 177-178
- Dragonflies, 100
- Drone, 201, 212
- Droplet method of infection, 622
- Drosophila, 457, 458, 461, 468, 525
- Dublin, Louis, 612
- Ductless glands, 391-402
- Duodenum, 291, 392
- Duplication, in chromosomes, 457
- Dura mater, 345
- Dustbowl, 592
- Dutch elm disease, 580, 581

- Ear, 361-362
 Ear drum, 362
 Early cleavage, 417, 418
 Earthworm, 67, 93, 103, 187-197, 188,
 334, 335, 409, 507
 circulatory system of, 190, 191
 cross section of, 193
 development of, 197
 digestive tract of, 189
 "hearts" of, 190, 191
 hermaphroditic, 195
 nephridium of, 192
 nervous system of, 194, 195
 reactions to stimuli, 194
 regeneration in, 198
 East, Dr. E. M., 465
 Echinodermata, 95, 103, 335, 343
 Echinoidea, 95
 Ecological balance, man's effect on, 577
 Ecology
 definition of, 1, 26
 how to study, 4, 5
 typical region, 2-4
 Economic value of plants and animals,
 573-579
 Ectoderm, 419
 Hydra, 180-181
 Ectodermal cells, 343
 Ectodermal derivatives, 422
 Ectoparasites, 219
 Ectoplasm
 Ameba, 154
 Paramecium, 158, 159
 Eddy, 278
 Edentata, 115
 Education, 437
 Eels, 499
 Effector, definition of, 375
 Effector cell, 341
 Effector neurons, 376
 Efferent fibers
 bee, 211
 earthworm, 195
 Egg shells, 422-423
 Eggs, 490, 503
 care of, by parents, 46
 theories regarding, in heredity, 466
 Egyptians, 561
 Eijkman, 278
 Einstein, 520
 Elasmobranchii, 107
 Elbow, 332
 Elements, in tissues, 277
 Elephant, 117, 545
 Elephant-fishes, 107
 Elephants and ancestors, range of, 31
 Elephas, 556
 Elimination of the unfit, 521
 Elk, 527
 Elliot, Dr. D. G., 535
 Elton, 215
 Embioidina, 100
 Embryonic membranes, 424-425, 427
 Embryology, 500
 Embryo sac, 177
 Emotional responses, 383-384
 Emus, 113
 Enamel, 286
 Endameba histolytica, 225, 422
 Endoderm, 281, 419
 formation of, in earthworm, 197
 Hydra, 181, 182
 Endodermal derivatives, 422
 Endomixis, 161, 417
 Endoplasm
 Ameba, 154
 Paramecium, 158, 159
 End organs, 340
 Endoskeleton, 235, 328, 329, 334, 336,
 532
 Endothelial muscle cells in Hydra, 181
 Endothelium, 304
 Endotoxins, 621
 Energy
 non-producers of, 276
 producers of, 276
 release in plants, 237
 Engelmann, experiment of, with oxygen
 release in algae, 258
 English, 561, 562
 Enterokinase, 297
 Environment, 431
 basic, 7
 factors of, 7-20
 effect of, in heredity, 435, 437, 517,
 522
 effect on diseases, 611-612
 man's effect on, 568-569
 Enzymes, 279, 280, 396
 inverting, 297
 production of, 127-128
 reversible, 280
 types of, in plants, 263-264
 Eoanthropus, 556, 560
 Eocene period, 476, 510, 511, 513
 Eohippus, 510, 511
 Eolithic division of Stone age, 547, 560
 Ephemerida, 100
 Ephippium, 413
 Epicanthic fold, 563
 Epidella melleni, 223
 Epigenesis, 431
 Epiglottis, 290
 Epimere, 425
 Epinephrine, 393
 Epipharynx, bee, 204
 Epiphytes, 23, 24
 Epithelial cells, 291

- Epithelio-muscular cells in *Hydra*, 180
 Epitrichian, 488
 Equilibration, 361
 Equisetum, 75
 Equus, 510, 511
 Eras of time, 475
 Erect mosaic, 358
 Erepsin, 295, 297
 Ergosterol, 279
 Erosion
 areas of in the United States, 591
 damage from, 590-592
 Erythrocytes, 303
 Eskimo, 561, 562
 Esophagus, 287, 288
 earthworm, 189
 Ethnology, 559
 Eucalyptus, 239
 Eugenics, 638, 639, 642
 Euglena, 77, 103, 281
 eyespot of, 375
 nutrition in, 157
 reproduction in, 157
 structure of, 156
 Euplectella, 79
 Euplotes, 335, 342, 343, 375
 Eurion, 563
 European corn borer, range of, 584, 585
 Euspongia, 79
 Eustachian tubes, 287
 Euthenics, 638-639
 Eutheria, 115
 Evaporation, effect of, on rise of water
 in plants, 269
 Evening primroses, mutations in, 525
 Evidence, scientific, of evolution, 495
 Evolution, 493-529
 Excretion, 319
 Exoascus, 73
 Exophthalmic goiter, 395
 Exoskeletons, 235, 328, 334, 336, 532
 Exotoxins, 621
 Expiration, 318
 Extensors, 327
 External nares, 284
 External respiration, 312, 313, 316
 Extra-embryonic coelom, 426
 Eye, physical adaptations in, 488, 492
 Eye brush, bee, 207
 Facets, 358
 Factor hypothesis, 450
 Factors, hereditary, 450, 458
 complimentary, 452
 inhibiting, 452
 sex-linked, 452
 supplementary, 452
 Factors of the environment
 biotic, 19-20
 chemical, 15-16
 gravity, 16
 light, 11-14
 molar agencies, 18-19
 substratum, 17-18
 temperature, 9-11
 water, 7-9, 8
 Falconiformes, 114
 Fangs, 493
 Fat metabolism, regulating principle
 of, 402
 Fat synthesis in plants, 262
 Fats, 276, 282
 Fatigue, muscular, 339
 Faunce, W. H. P., 638
 Federal agencies, 603-604
 Federal bird and game refuges, 601
 Feet, adaptations of, 333
 Female pronucleus, 417
 Femur, 332
 insect, 206, 207
 Ferns, 75, 498
 Fertilization, 414, 416, 456
 definition of, 62
 earthworm, 196-197
 moss, 176
 results of, 417
 Fibrin, 311
 Fibrinogen, 311
 Fibula, 332
 Filicineae, 75
 Fins, 498
 Fire, use of, 550
 First polar body, 430
 Fish, 499, 501, 532, 547
 armored, 334
 heart of, 497
 physical adaptations in, 491
 rise of, 513
 Fisheries, 595-596
 Bureau of, 604-605
 Fission, 411
 Flagella, 334
 bacteria, 165
 Flame cells, 320
 Flatworms, 85, 103, 344, 485, 532
 Flemings, 562
 Fleas, 216
 Flexors, 327
 Flexures, 347
 Flies, 102
 Flints, 547, 548
 Florissant shales, 511
 Flower, function of, 272
 Flowering plants, rise of, 513
 Fluctuating variations, 572
 Flukes, 85, 103, 219
 Fluorine, 277
 Follicular cells, 399

- Food, 275, 297
 of fishes, 577
 Food chains, 51
 Food getting in plants, 53-54
 Food making in green plants
 factors in, 253-254
 summary of, 270
 Food tube, worker bee, 209
 Foot, evolution of, 543
 Forage plants, 515
 Foramen magnum, 352
 Foraminifera, 328, 478
 Forbes, Prof., 577
 Fore-brain, 346
 Forest fires, 592
 relation to floods, 590
 Forest products, 574, 593-594
 Forest service, work of, 593-595
 Forest waste, 592-593
 Forests
 enemies of, 593
 usefulness of, 589-590
 Fossils, 477-480, 510, 533, 554
 Four-o'clock, 446
 Fovea centralis, 360
 Fowl, 514
 Fragillaria, 71
 Fragmentation, 411
 Fraunhofer's lines, 256, 257
 Free-martin, 398, 471
 French, 561
 Fresh-water mussel, life history of, 598
 Frogs, 103, 109, 336, 491, 540, 545
 Fruit fly, 525
 Fucus, 71
Funaria
 gametophyte of, 175
 life cycle of, 175
 sporophyte of, 174
 Fundus, 288
 Fungi, 71, 228
 harm done by, 579-580
 method of nutrition in, 174
 Funiculus, ventral, lateral, and dorsal, 353
 Gaertner, 442
 Galapagos Islands, 508
 Galen, 305
 Galileo, 495
 Gall, 218
 Galliformes, 114
 Gall insects, 218
 Galtsoff, 35
 Gametes, 411, 446, 460
 Ulothrix, 171
 Gametocytes, 228
 Gametogenesis, 428
 Gametophytes, 498
 development of in flowering plants, 177
 Gametophyte generation, evolution of, 178
 Ganoidei, 107
 Garden of Eden, biological, 564-565
 Garpiki, teeth of, 285
 Gastric gland, 293, 294
 Gastric lipase, 294
 Gastric mill, 282
 Gastropoda, 97
 Gastrotricha, 89
 Gastrovascular cavity, 281
 Hydra, 181-182
 Gastrovascular system, 301
 Gastrula, 418
 Gastrulation, 418
 earthworm, 197
 Geese, 114
 Gemmule, 410, 491
 Genes, 430, 431, 435, 456, 457, 461, 640
 subtraction of, 414
 Genetics, 434, 435, 516
 Genial tubercles, 552
 Genotype, 446, 449
 Genus, concept of, 64-68
 Gephyrea, 93
 Germans, 561, 562
 Germ cells, 412
 addition of, 414
 Germinal selection, 527
 Germ plasm, 438-439, 466, 526, 640
 Gestalt psychology, 385
 Gibbons, 537, 538
 Gill arches, 329
 Gill books, 314
 Gills, 315
 Giraffe, 117, 495, 508, 517, 519
 Girdle
 hip, 332
 pectoral, 332
 pelvic, 332
 shoulder, 332
 Gizzard, 288
 Glabella, 563
 Glacial period, 513, 560
 Gland cell, 341
 Glands
 duodenal, 292
 gastric, 290
 lymph, 304
 intestinal, 292
 Gloecapsa, 69
 Glomerulus, 323, 324
 Glottis, 287, 317
 Glucose, 279, 280, 295, 298
 Glycerin (glycerol), 295, 298
 Glycogen, 296, 298

- Glycosuria, 401
 Gnathion, 563
 Gnathostomata, 507
 God, ideas concerning, 494
 Goethe, 497
 Goiter, 395
 Golden plover, 490
 Gonad stimulation, 400
 Gonad transplantation, 471
 Gonads, 397, 398
 Gonotheca, Obelia, 185, 186
 Gordiacea, 87
 Gordius, 87
 Gordon, R. B., 262
 Gorilla, 508, 537, 538, 539, 545
 Grand Canyon, 474
 Grantia, 79
 Grasshopper, 99, 506, 519
 mouth parts of, 201
 physiological adaptations in, 483
 structural adaptations in, 486
 vagrant, 200
 Gravity, effect of, on plants, 16
 Gray matter, 340, 353
 Grebes, 113
 Greeks, 561
 Gregariousness, 492
 Grijns, 278
 Gristle-fishes, 107
 Ground pines, 75
 Growth curve, inflorescence in *Yucca*, 271
 Growth of cell, 415
 Growth stimulation, 400
 Grubs, yellow, 230, 232
 Gruiformes, 114
 Guanaco, 509
 Guard cells, 251, 252, 267
 Guinea pig, 438, 515
 Gulick, 523
 Gulls, 114
 Gymnospermae, 75
 Gynandromorphs, 471
 Gypsy moths, 519
 Habits, formation of, 379
 Haeckel, 501
 Hair color, 563
 Hair form, 563
 Hairiness, 563
 Hairworms, 87
 Hales, Stephen, 241, 267
 Hands, 547
 Hanson, 396
 Haploid number, 429
 Hard palate, 284
 Harrington, 394
 Harrison, 432
 Harvey, William, 305, 408, 528
 Hawks, 114
 Hay fever, 394, 632
 Head fold, 426
 Head piece, sperm, 416
 Health, definition of, 609
 Health work, expenditures for, in the United States, 635
 Hearing, 361
 Heart, 306-308, 307, 488, 497
 beating of, 308
 insect, 209
 Heart action, bee, 209
 Heart muscle, 338
 Heart-wood, 246-247
 Heath hen, 599
 Hedgehog, 534
 Heidelberg jaw, 556, 565
 Hemichordata, 105
 Hemiptera, 101
 Hemitrichia, 71
 Hemoglobin, 312
 Hemophilia, 311
 Henle, 391
 Hens, breeding of, 453
 Hepaticae, 73
 Herbaceous plants, 240
 Herbivorous animals, teeth of, 52
 Heredity, 435, 437, 522, 640
 Hermaphrodites, 471
 Hermaphroditism, 412
 Hermit crab, 490
 Herriek, C. J., 388
 Hertwig, O., 503
 Hesperornithiformes, 113
 Hessian fly, 585
 Hexactinellida, 79
 Hibernation, definition of, 10
 Hind-brain, 346
 Hippidium, 511
 Hippopotamus, 543
 Hirudinea, 93
 Histology, definition of, 138
 Hitecock, 479
 Hodge, Prof., 383
 Hog, 515
 Holocephali, 107
 Holophytic nutrition, 281
 Holothuroidea, 95
 Holozoic nutrition, 281
 Homarus, 500
 Homologous bones, 498
 Homology, 67
 Homoptera, 101
 Homo heidelbergensis, 556, 560
 Homo neanderthalensis, 557
 Homo sapiens, 530, 557, 559, 560, 561
 Honey bee, 201-202, 203, 550
 life history of, 212, 213
 Honey manufacture, 208

- Honey stomach, bee, 208, 209
 Hoofs, 493
 Hooke, Robert, 138, 311
 Hookworm, 216
 control of, 616
 infection by, 615-616
 larvae of, 223
 life cycle of, 223-224
 Hooton, 544, 552, 563
 Hormiphora, 83
 Hormones, 310, 391, 396, 399, 402, 467
 sex, 471
 Hornaday, W. T., 537, 599
 Horns, 493
 Horses, 447, 477, 487, 515, 541, 544, 545
 blood relationship of, 514
 evolution of, 511, 512, 513
 wild, 557
 Horseshoe crab, 514
 Host, 217
 Host-parasite conflict, 217
 Host-parasite equilibrium, 217
 Host-parasite relationships, 217
 Hotsprings, 491
 House fly, 336
 foot of, 617
 Houseman, Laurence, 496
 Houssay, 401
 Howard, Dr., 568
 Howell, A. H., 578
 Hrdlicka, 555, 561
 Humerus, 332
 Humming bird, 545
 Hurst, C. C., 470, 503
 Huxley, 500, 516
 Hybrid vigor, 455
 Hybrids, 441
 Hydra
 budding in, 184
 digestion in, 182
 locomotion in, 180
 maturation in, 183, 184
 nerve net of, 183
 neuro-sensory cells in, 183
 reaction to stimuli by, 182-183
 regeneration in, 184
 reproduction in, 183-184
 reproductive organs of, 184
 respiration in, 182
 Hydroids, 185-186, 334
 Hydrolase, 280
 Hydrolytic, 280
 Hydrophytes, 5
 Hydrotheca, 185
 Hydrozoa, 81
 Hygroscopic, 176
 Hymenoptera, 102
 parasitic, 221
 Hyoid, 329
 Hyperglycemia, 401
 Hyperosmotic, definition of, 136
 Hyphae, mold, 173
 Hypnotoxin, 180
 Hypohippus, 511
 Hypomere, 425
 Hypophysis, 348, 399
 Hyposmotic, definition of, 136
 Hypostome, 179
 Hyracoidea, 117
 Ichneumon fly, 46, 221
 Ichthyopsida, 507
 Ichthyornithiformes, 113
 Identical twins, 432
 Igorots, 561
 Ileo-caecal valve, 292
 Imago, bee, 213
 Immunity, 489
 active, 627-632
 definition, 625
 mechanism of, 626-627
 passive, 632-634
 racial, 625-626
 types of, 625-626
 Inbreeding, 454
 Incas, 562
 Incisors, 286, 563
 Inclusions, cell, 129
 Incubation period in diseases, 635
 Independent assortment, 446, 447, 450,
 458, 460
 Indeterminate cleavage, 432
 Indians, 562
 Inferior vena cava (postcava), 307
 Influenza, 624-625
 Infraesophageal ganglion, 344
 Infundibulum, 348, 400
 Infusoria, 77
 Ingen-Hausz, 241
 Inheritance, 522
 criss-cross, 470
 cytoplasmic, 463
 extra-biological, 436
 maternal, 464
 social, 436
 Inner ear, 361
 Insect pests, enemies of, 587
 Insect poisons, 588
 Insecta, 99, 103
 Insectivora, 115
 Insectivores, 534, 540
 Insects, 99, 103, 234, 315, 334, 336,
 344, 513, 521, 532
 body plan of, 200-203, 202
 casual carriers, 618
 characteristics of, 200-201, 202
 damage by, 583, 586
 diseases carried by, 617-621

- methods of controlling, 587-588
- predatory as carriers, 618-619
- Insertion, of muscle, 337, 338
- Inspiration, 318
- Insulin, 296
- Insight, 365
- Intelligence, definition of, 384-385
 - in apes, 386-388
 - in man, 388
 - measure of, 389
- Intelligence quotient, definition of, 388
- Intercostal muscles, 318
- Interference, in heredity, 457
- Intermediate lobe, pituitary, 402
- Intermedin, 402
- Internal nostrils, 287
- Internal respiration, 312, 316
- Inter-relationships
 - between members of same species, 45-48
 - between plants and animals, 59
- Interrenal, adrenal, 392
- Interstitial cells, 399
- Intestinal glands, 295
- Intestine
 - earthworm, 189
 - insect, 209
- Intracellular excretion, 320
- Inversion, in heredity, 457
- Invertase, 297
- Invertebrate nervous systems, 340
- Invertebrates, 103, 328, 335
- Iodine, 277
- Iris, 359, 492
- Iron, 277
- Iron age, 547
- Islands of Langerhans, 296, 397
- Isolation, 518, 523
- Isolecithal, 418, 421
- Isoptera, 100
- Isosmotic, definition of, 136
- Italians, 561
- Jacana, 487
- Japanese beetle, range of, 583, 585
- Japanese chestnut blight, 580
- Jastrow, Joseph, 437
- Java man, 555-556
- Jaw, Heidelberg, 556, 565
- Jaws, 329
- Jeans, 407
- Jellyfishes, 81, 103, 333, 485, 507
- Jenner, Edward, 628
- Jennings, H. S., 369, 464
- Jews, 561
- Johannsen, 457
- Jones, D. F., 572
- Jordan, 523
- Jordan and Kellogg, 29
- Jugular vein, 304
- Jungle-fowl, 515
- Jurassic period, 476, 513
- Kala azar, 620
- Kangaroo, 542
- Katabolism, definition of, 126
- Katydid, 524
- Kellogg, Vernon L., 524
- Kelvin, Lord, 562
- Kendall, 394
- Kidneys, 321, 322, 323, 488, 498
- Kingsley, 499
- Kipling, 505
- Kiwis, 113
- Klamath River, fishing in, 15
- Knight, 442
- Knight, experiment of, with plants, 371-372
- Koch, R., 622
- Koelreuter, 442
- Köhler, W., 386-387
- Krakatao, repopulation of, 34-35
- Krogh, 303
- Labellum, 203, 205
- Labial palps, 203, 205
- Labium, 201, 203, 205
- Labrum, 201, 203, 205
- Lachrymal gland, 360
- Lactase, 297
- Lactation hormone, 400
- Lacteals, 291, 292, 298
- Lactic acid, in muscles, 339
- Lake-dwellers, 452
- Lamarck, 516, 517, 519, 522, 526
- Laminaria, 71
- Lamprey eel, 221
- Lamp-shells, 91, 328
- Land-inhabiting forms, 333
- Language, 551
- Lankesteria, 77
- Lanugo, 488, 501
- LaPlace, 312, 407
- Large intestine, 291, 292
- Larva
 - bee, 212
 - coelenterates, 186
- Larynx, 329
- Lateral fold, 426
- Lateral line, 363
- Lavoisier, 312
- Law of Priority, 66
- Leaf
 - adaptations for movement in, 374
 - cross section of, 252
 - functions of, 253-270
 - of sensitive plant, 374
 - structure of, 251-253

- Leaf arrangement, 259
 Leeches, 93, 103
 Leg
 fore, 332
 hind, 332
 Legs, evolution of, 532, 543
 of worker bee, 207
 Lemurs, 115, 514, 535, 536, 545
 Lens, 359, 360
 Lenticels, 248
 Lepidoptera, 102
 Leptorhynchoides, 87
 Leuckhart, 467
 Leucocytes, 303
 Leucoplasts, 465
 Lice, 216
 head, 223
 Lichen, 55
 Liebig, 312
 Life
 in air, 23-24
 definition of, 126
 in the hive, 213
 in water, 21-23
 on land, 24-25
 signs of, 127
 Life realms, 42, 43
 Life zones, 41-42
 Light, 490, 492
 a stimulus, 14
 Light-perceiving organ, 344
 Light receptors, 357
 Lignin, 264
 Ligula, 203, 205
 Limax, 97
 Limestone, 478
 Limulus, 314, 499, 514
 Linin fibers, 141
 Linkage, 458-461
 Linnaeus (Linné), 64, 65, 66, 506, 517, 530
 Linophryne, 491
 Lion, 508
 Lipase, 280, 295
 Liver, 293, 296, 321
 Liver fluke, 490
 Liverworts, 73
 Living matter, chemical organization
 of, 130-131
 Lizards, 103, 111, 499, 514, 532
 Llama, 508, 509
 L'Obel, Matthias, 64
 Lobsters, 99, 333, 500
 Locomotion
 the "why" of, 334
 ways of, 38-40
 Locomotor organs, 233, 334
 Locust, sex inheritance in, 467, 468
 Loeb, Jacques, 357, 367-368
 Loons, 113
 Louse, body, 620
 Lumbar plexus, 497
 Lumbricus, 93
 Lung books, 313
 Lung-fishes, 107
 rise of, 513
 Lungs, 316, 322
 Lycopodium, 75
 Lycopsida, 75
 Lymph, 298, 299, 304
 Lymphatic system, 304
 Lymph nodes, 292, 304
 Lymphocytes, 304
 Lysins, 626
 Lytic power of parasites, 217
 Macaques, 537
 MacDougal, D. T., 251
 McClung, 467, 468
 McCollum, 278, 279
 MacCurdy, 549, 553
 McIndoo, 204
 Macleod, 296, 397
 Macrolecithal, 421
 Macronucleus, Paramecium, 160, 161, 162
 Macropus, 115
 Macula lutea, 360
 Madreporite, 335
 Magellania, 91
 Magnesium, 277
 Maize, 457, 515
 Malaria, 220
 economic importance of, 618-619
 life cycle of, 227
 preventive measures for, 618-619
 Malays, 562
 Male pronucleus, 417
 Mallophaga, 100, 524
 Malpighi, 209
 Malpighian corpuscle, 324
 Malpighian tubules, 209, 321
 Maltase, 280, 295, 297
 Malthus, 519
 Maltose, 293
 Mammalia, 103, 115
 Mammals, 488, 491, 497, 501, 513, 533, 553
 conservation of, 600
 Mammary glands, 489
 Mammoth, 478, 557
 Man, 115, 513, 532, 545, 553, 637, 638
 parasitic worms of, 613-614
 Mandibles
 bee, 203, 205
 locust, 201
 Mandrill, 537
 Marchantia, 73

- Market gardening, 574
- Marmoset, 508, 545
- Marsupials, 115
- Mast, S. O., 154, 155
- Mastax, rotifers, 153
- Mastigophora, 77
- Matthews, 565
- Matthews' Law, 565
- Maturation, 428, 456
- Maxilla
 - bee, 203, 205
 - locust, 201
- Mayas, 562
- Mayflies, 100
- Mayo, John, 311
- Mead, A. D., 413, 529
- Mechanisms of response
 - animals, 374-376
 - plants, 370-374
- Mechanisms of sensation and co-ordination, 340
- Mecoptera, 102
- Medulla, adrenal, 392
- Medulla oblongata, 310, 318, 346, 351, 353
- Mediterranean fruit-fly, 585
- Mediterranean races, 561
- Medullary sheath, 341
- Medusae, Obelia, 186
- Meiosis, 459
- Melanesians, 562
- Membrane
 - plasma, 134
 - selectively permeable, 134
- Mendel, 278, 442, 443-452, 459, 523, 640
- Mendelism, 443, 515, 640
- Mendel's laws, 455, 467
- Mental age, 388
- Meridion, 71
- Meristem, 243
- Merozoite, 227
- Mesencephalon, 346, 350
- Mesenchyme cells, 419
- Mesoderm formation, 419
 - in earthworm, 197
- Mesodermal derivatives, 422
- Mesohippus, 511
- Mesomeral, 425
- Mesophyll, 252
- Mesophytes, 6, 7
- Mesozoic era, 476, 513, 533, 553
- Metabolic gradients, 381, 431
- Metabolism, definition of, 126
- Metacarpal bones, 332
- Metagenesis, 414
- Metameres, earthworm, 187
- Metamerism
 - earthworm, 187
 - insect, 200
- Metamorphosis, 235
 - honey bee, 212-213
- Metaphase, 142, 143
- Metatarsal bones, 332
- Metatarsus, bee, 207, 208
- Metatela, 351
- Metatheria, 115
- Metazoa, 139
- Metencephalon, 346, 350
- Method
 - experimental, 441
 - germplasmal, 441, 455
 - observational, 440
 - statistical, 440
- Metridium, 81
- Mexican axolotl, 414
- Mice, 487
- Micro-conjugant, 412
- Micronucleus, Paramecium, 160, 161, 162
- Microsphaera, 73
- Microstomum, 411
- Micrura, 85
- Mid-brain, 346, 350
- Middle ear, 329, 362
- Middle piece, sperm, 415, 416
- Mildews, 228
- Millipedes, 99, 103
- Milton, John, 493
- Minkowski, 397
- Miocene period, 476, 511, 513
- Mirabilis jalapa, 446
- Miracidium, 219
- Mistletoe, 217, 223
- Mites, 102
- Mitochondria, 416
- Mitosis, 141-144, 415, 456, 459
 - animal, 143
 - plant, 141
- Mixed nerves, 353
- Moas, 113
- Modified ratios, 450-452
- Molars, 286
- Molds, 71
 - bread, 173-174
 - fossil, 478
 - reproduction in, 174
- Moles, 115, 534
- Molluscoidea, 91, 103
- Mollusca, 97, 103
- Molluscs, 235, 499, 513
- Molting, 234
- Mongolians, 562
- Monkeys, 233, 487, 507, 514, 535, 536, 537, 546
- Monocotyledonous stem, 249-251, 250
- Monocotyledons, 64, 75, 77, 240
- Monohybrids, 447
- Monotremes, 115, 423

- Moose, 509
 Morchella, 73
 Morgan, 458, 461, 462, 468, 469, 502, 503
 Mosquitoes, 102, 216, 222
 Anopheles, 228
 Culex, 228
 mouth parts of, 487
 Mosses, 73, 498, 506
 Moths, 468
 Motion, the "Why" of, 334
 Motorium, 343, 375
 Mouse, 495, 499
 Mouth parts, homologous, 486, 487, 488
 Movement, devices for, 334
 Mucor, 71
 Mucosa, 289
 Mucous membrane, 284
 Müller, Johannes, 391
 Multiplication of cells, 415
 Murex, 505
 Musci, 73
 Muscle cell, 341
 Muscle bands, 339
 Muscles and muscular systems, 336-340
 Muscles
 circular, 335, 337
 earthworm, 192-193
 exoskeletal, 336
 fusiform, 338
 heart, 336
 inner longitudinal, 335
 involuntary, 327, 336, 337
 longitudinal, 337
 origin of, 337, 338
 skeletal, 336, 337, 338
 smooth, 327, 336, 337
 striated, 336, 337, 339
 voluntary, 327
 Muscular activity, 339
 Muscular contractions, 339
 Muscular relaxation, 339
 Musculature, human, 337, 338
 Mussels, 333
 Mutations, 442, 524-525
 Mutual aid, 48
 Mycelium, mold, 173
 Mycorrhiza, 55
 Myelencephalon, 346, 351
 Myology, 327
 Myriapoda, 99, 103, 315
 Myriapods, 532
 Mystacoceti, 117
 Myxomycetes, 71
 Myxosporidia, 77
 Naididae, 411
 Nannoplankton, 22
 Nasion, 563
 National Parks and Forests, 605
 Native behavior patterns, 377-378
 Natural potencies, 432
 Natural selection, 443, 518, 524
 Naudin, 442
 Navicula, structure of, 163
 Neanderthals, 557, 560
 Necator americanus, 223
 Neck, 286
 Necturus, 109
 Needham, 406
 Negroes, 562
 Nekton, 22
 Nemalion, 71
 Nemathelminthes, 87, 103
 Nematocysts, 180
 Nematoda, 87
 Nemertinea, 85
 Neolithic division of Stone age, 547, 560
 Neornithes, 113
 Nephridia, earthworm, 192
 Nephroi, 488
 Nephrostome, 192, 320
 Nereis, 93
 Nerve cell, 340, 343
 Nerve cord, 233
 Nerve impulse, 339
 Nerve net, 343
 Hydra, 183
 Nerve ring, 343
 Nerves, peripheral, 340
 Nervous system, 233
 bee, 211
 physiological unit, 341
 protective devices for, 343
 types of, 342, 376
 unit of structure, 340
 Nest-building, a genetical adaptation, 490
 Netherlands, 562
 Neural groove, 420
 Neurilemma, 340
 Neuromotor apparatus, 335, 342
 Neuron, 340
 definition of, 195
 Neuroptera, 100
 Nitella, 71
 Nitrogen cycle, 60
 Nitrogenous wastes, 319
 Nodes, lymph, 304
 Noguchi, 619
 Nolan, 212
 Non-chordates, 328
 Non-disjunction, 456, 457
 Nordic races, 561
 Norman, J. R., 45
 Nostoc, 69
 Nostrils, 284, 317
 Notochord, 69, 233, 329

- Nutrient solutions for plants, 242
- Nutrition, plant and animal compared, 167
- Nucleus, 130, 456, 465
- Obelia, 81, 414
 - life cycle of, 185
- Ocelli, bee, 203
- Octopus, 97
- Odonata, 100
- Odontoceti, 117
- Odor, perception of, in bees, 204-205
- Oedogonium, 69
 - structure of, 172-173
- Oenothera, 525
- Oestrin, 399
- Oil
 - in plants, 264-265
 - occurrence of, 479
- Okapi, 508
- Olfactory bulbs, 347
- Olfactory lobes, 347
- Olfactory nerve, 352
- Olfactory pits, bee, 205
- Oligocene period, 476, 511, 513, 554
- Ommatidia, 205, 206, 358
- Onychophora, 99, 103
- Oögenesis, 430
- Oögonia, 430
 - Oedogonium, 172
- Öökinete, 228
- Oöspore, Oedogonium, 172
- Operculum, moss, 176
- Ophioglyphs, 95
- Ophiuroidea, 95
- Opisthocranium, 563
- Opsonins, 626
- Optic chiasma, 352
- Optic lobes, 350
- Optic nerve, 352, 358
- Optic stalks, 350
- Oral (buccal) cavity, 284
- Oral groove, Paramecium, 158, 159
- Orang-utan, 537, 539
- Orbit, 358
- Orchard fruits, 574
- Orchard heaters, 10
- Ordovician period, 476, 513
- Organ, 506
- Organ of Corti, 362, 370
- Organismal theory, 139, 365
- Organisms
 - definition of, 148-149
 - shifting of, 34-38
- Organizers, 432
- Organogeny, 414
- Origin of life, 406, 407
- Ornithorhynchus, 115
- Orohippus, 511
- Orthogenesis, 527
- Orthoptera, 99
- Osborn, estimate of geological time by, 553
- Osborn, Henry F., 407
- Osborne, 278
- Oscillatoria, 69
- Osmosis, 135
- Osmotic pressure, in plants, 135-136
- Ostia, insect heart, 209
- Ostium, 302
- Ostracoderms, 105
- Ostriches, 113, 545
- Otocyst, 372
- Otoliths, 361, 372
- Outbreeding, 455
- Ova, 415, 430
- Ovary, 412, 415
- Overpopulation, 518, 519
 - results of, 34
- Oviducts
 - bee, 212
 - earthworm, 196
- Ovipositor
 - bee, 202
 - queen bee, 212
- Ovists, 466
- Owls, 114
- Ox botfly, 221, 222
- Oxidase, 280
- Oxygen, 318
 - production of, by green plants, 269
 - release of, by green plants, 269-270
- Oxyhemoglobin, 303, 312, 316, 317
- Oysters, 97, 103
- Pack, C. L., 581
- Paedogenesis, 414
- Pain receptors, 363
- Palatine ridges, 284
- Palatine tonsils, 287
- Paleocene period, 476, 513
- Paleolithic division of Stone age, 547, 560
- Paleontology, 473, 482
- Paleotherium, 511
- Paleozoic era, 476, 478, 513, 553
- Paleozoic period, 512, 513
- Pallium, 348
- Palolo worm, 411
- Pancreas, 293, 295, 396
- Pangenes, 522
- Pangeneses, 522, 526, 527
- Papillary muscles, 308
- Pappataci, 620
- Parahippus, 511
- Paramecium, 77, 157-163, 316
 - locomotion of, 159-160
 - structure of, 159

- Parasites, 215
 blood-inhabiting, 219
 digestive tract of, 219
 eggs of, 219
 external, 216, 219, 221
 indirectly acquired, 617-621
 internal, 216, 223
 maintenance of cycle, 220
 periodic, 216, 222
 permanent, 216, 223
 relationships of, 216
 reproductive capacity of, 219
 requiring one host, 223
 requiring more than two hosts, 229
 requiring two hosts, 225
 respiration of, 219
 temporary, 216, 221
 Parasitic diseases, 634-635
 Parasitic Hymenoptera, 221
 Parasitic life, effects of, 218
 Parasitic worms, harm caused by, 582
 Parasitism
 as a biological adaptation, 492
 art of, 215
 Parasympathetic, 354
 Parathyroid, 396
 principle of, 402
 Parenchyma, 245, 252
 Park, Wm. H., 623
 Parker, experiment with sea anemone, 382
 Parotid gland, 293
 Parrots, 114, 488, 552
 Pars intermedia, 402
 Pars nervosa, 400, 402
 Pars tuberalis, 400
 Parthenogenesis, 413, 471
 in mammals, 413
 Parthenogenetic agents, 413
 Passeriformes, 114
 Passive immunity, 632-634
 Pasteur, 407, 631-632
 Pasteur Institute, 632
 Pathogens, 621
 Pavlov, work of, 379-380
 Peas, garden, 444, 445, 454, 459
 sweet, 451
 Peccary, 508
 Pectin, 244
 on bee's leg, 207, 208
 Pectinatella, 91
 Pectoral girdle, 332
 Pedigree breeding, 453
 Peking man, 565
 Pelecypoda, 97
 Pellicle, structure of, in *Paramecium*, 158
 Pelvic girdle, 331, 332
 Pelvis (of kidney), 323
 Penguins, 113
 Penn, William, 639
 Pentacrinus, 95
 Pentadactyl limb, 332
 Pepsinogen, 294
 Peptones, 294
 Perching birds, 114
 Perennial, 240
 Period
 post glacial, 476
 recent, 476
 time, 475
 Periosteum, 338
 Peripatus, 99
 Peripheral nervous system, earthworm, 194
 Perisarc, 185
 Perissodactyla, 117
 Peristalsis, 290, 291, 294
 Peristome, moss, 176
 Permian period, 476, 513
 Perpetuation of species, 335
 Persians, 561
 Petals, 497
 Petiole, 250-251
 Petrifications, 478
 Petromyzon, 105
 Pettenkofer, 312
 Pettersson, 35
 Peyer's patches, 292
 Phaeophyceae, 71
 Phagocytes, 626
 Phalanges, 332
 Pharyngeal tonsils, 287
 Pharynx, 287
 earthworm, 189
 Phascolosoma, 93
 Phenotype, 446, 449
 Phillips, 438
 Philodina, 89
 Phloem, 243, 246, 247, 248, 250
 Phoenicians, 561
 Phoronidea, 91
 Phoronis, 91
 Phosphorus, 277
 Photoreceptors, 358, 359
 Phycomycetes, 71
 Phyla, 65
 Phyllophora, 71
 Phylogeny, 501
 Physalia, 81
 Pia mater, 345
 Pig, 514, 515
 Pigeons, 114, 335
 Piltdown man, 556, 565
 Pincus, 413
 Pineal eye, 350
 Pineal gland, 397, 398
 Pines, 75

- Pisces, 103, 105
- Pistils, 497
- Pithecanthropus, 555, 560, 637
- Pith rays, 247, 249
- Pituitary gland, 348, 397, 398, 399
 - anterior lobe, 400
 - intermediate lobe, 400
- Placenta, 427, 428
- Planaria, 85
- Plankton, 13, 14, 21, 22
- Planta, bee, 207
- Plant and animal cells, functional
 - differences, 166-167
- Plant breeding, methods of, 571-573
- Plantigrade feet, 333
- Plant lice, 413
- Plant parasites, 216, 223, 288
- Plants
 - harm done by, 579-582
 - long and short day, 12, 13
 - parts of, 238-240
 - rôle of green, 237-273
 - small, in fresh water, 153-154
 - types of, 239
- Plants and animals
 - cells of, 139-140
 - economic values of, 573-579
- Planula, Obelia, 185, 186
- Plasma, 303
- Plasmodium, 77, 227
- Plasmolysis, 136
- Plastids, part played by, in heredity, 465
- Platelets, 311
- Platyhelminthes, 85, 103
- Plecoptera, 100
- Pleistocene period, 476, 477, 509, 513, 553, 554, 555, 557, 560, 565, 637
- Plesippus, 511
- Pleurococcus, 169
- Plicae circulares, 284, 291
- Pliocene period, 476, 511, 513, 555
- Plihippus, 511
- Ploidy, 457
- Plovers, 114
- Poëbrotherium, 509
- Poisons, honey bee, 212
- Polar bodies, 430
- Polarity, 381
- Poles, 561
- Poliomyelitis, 620
- Pollen basket, 207
- Pollen brush, 207
- Pollen comb, 207, 208
- Pollen grains, 177
- Polygordius, 93
- Polynesians, 562
- Polyps, 81
 - Obelia, 185
- Polysiphonia, 71
- Polystoma, 85
- Pons varolii, 350
- Populations, factors in changing, 34-38, 41
- Porcupines, 505
- Porifera, 79, 103
- Portuguese, 561
- Posterior lobe, pituitary, 400, 402
- Posterior nares, 287
- Posterior peduncles, 351
- Post-glacial period, 476, 513
- Potassium, 277
- Poultry, 515
- Precipitins, 626
- Preformation, 431
- Premolars, 286
- Pressure
 - effect on adaptations, 490, 491
 - oxygen, 316
- Pressure receptors, 362, 363
- Priestley, 312
- Primary oöcytes, 430
- Primary spermatocyte, 429
- Primates, 115, 233, 534, 540, 541
- Primitive streak, 420
- Primitive vascular plants, 75
- Primordial germ cells, 428
- Primroses, 436
- Proboscidea, 117
- Proboscis, bee, 204, 205
- Procamelus, 509
- Procellariiformes, 113
- Prochordates, 340
- Progesterin, 399
- Proglottid, 226
- Prophase, 141, 142
- Propolis, bee glue, 213
- Prosecretin, 392
- Prosencephalon, 346
- Prostomium, 188
- Protection of embryo, 422
- Protective coloration, 492
- Protein elimination, 321
- Proteins, 276, 282
 - in plant synthesis, 262
 - split, 621
- Proteocephalus ambloplitis*, 229, 230
- Proteoses, 294
- Proterozoic era, 475, 476, 513
- Protonema, moss, 176
- Protoplasm
 - colloidal nature of, 132-133
 - composition of, 128, 131-132
 - in cell, 128-130
- Protoplasmic extensions, 335
- Protoplasmic strands, 338
- Protoplast, 169
- Protopterus, 107
- Prototheria, 115

- Protozoa, 77, 103, 151-163, 328, 334,
 335, 342, 411
 disease-causing, 582
 parasitic, 220
 Protozoans, 234, 485, 511, 531
 Protracheates, 315
 Protylepus, 509
 Psalterium, 288
 Pseudopodia, 334, 342
 Psilotum, 75
 Psychozoic era, 476, 513
 Pterodactyls, 513
 Pteropsida, 75
 Ptyalin, 293
 Puff balls, 73
 Pulmonary artery, 308, 317
 Pulmonary circulation, 309
 Pulp cavity, 287
 Pulvini, function of, 374
 Pupa, bee, 212, 213
 Pupil, 359
 Pygmies, 561, 562
 Pylorus, 289
 Pyramidal tracts, 351
 Pyramids, 351
 Pyrenoids, 170

 Quarantine, reasons for, 635
 Queen bee, 201, 205, 211, 212, 214
 Queen cell, 212

 Rabbit brush, 50
 Rabbits, 493, 499, 514, 515
 Rabies, 632
 Raccoons, 115, 546
 Race horses, 453
 Races, 559
 Radial canals, 336
 Radial nerve cords, 343
 Radial symmetry, 343, 531
 Radio-activity, use of, for estimating
 geological formations, 554
 Radiolaria, 77, 328
 Radius, 332, 544
 Rails, 114
 Rana, 109
 Rancho La Brea, 477
 Rathke's pocket, 399
 Ratios, modified, 450
 Rats, 115, 545
 Ray, John, 64
 Reactions to stimuli, 366, 368
 Recapitulation theory, 501
 Receiving neurons, 375
 Receptor-effector system, 343
 Receptor neuron, 341
 Receptors, 376
 Recessive characters, 445, 454
 Rectum, 292

 Redi, 406
 Rediae, 413
 Reduction division, 429
 moss, 176
 Oedogonium, 173
 Spirogyra, 171-172
 Reed, Walter, 619
 Reflex actions, 342, 376
 Reflex arcs, 341
 Regeneration, 408
 in arthropods, 410
 in Hydra, 409
 in Planaria, 409
 in starfish, 409
 in vertebrates, 410
 Reindeer, 559
 Rejuvenescence, 417
 Relations
 between different species, 50-51
 between flowers and insects, 61-62
 Renal corpuscle, 323, 324
 Renal pyramids, 323
 Renal tubules, 322, 323
 Repetition theory, 502, 503
 Reproduction, 410
 bee, 211-212
 plants, 61, 62, 270-272
 Reproductive organs, earthworm, 196
 Reproductive polyp, Obelia, 185, 186
 Reproductive system, earthworm, 195-
 196
 Reptilia, 103, 111, 329, 487, 497, 501,
 513, 533
 fossil armored, 334
 Resistance to bacteria, 623
 Respiration
 external, 311
 Hydra, 182
 internal, 311
 plant, 265-266
 Respiratory center, 318
 Respiratory papillae, 313
 Respiratory trees, 313
 Responses
 causes of, 366
 to gravity, plants, 371-373, 372
 to stimuli, nature of, 369-370
 to water, roots, 370, 373, 374
 Reticulum, 288
 Retina, 359, 360
 Reticular cells, 358
 Rheas, 113
 Rheiformes, 113
 Rhinoceros, 117, 508, 556, 557
 Rhizoids, mold, 173
 Rhodophyceae, 71
 Rhombencephalon, 346
 Rhynchocephalia, 111
 Rhynia, 75

- Rhythms of plant life, 23
 Ribs, 331
 Ricca, 73, 371
 Riddle, Oscar, 467
 Rind, 250
 Ring canal, 336
 Ritter, W. E., 528
 Rockefeller Sanitary Commission, control of hookworm by, 616
 Rocky Mountain spotted fever, 222
 Rodentia, 115
 Rods and cones, 358, 359, 360
 Rogers, 391
 Root
 dicotyledonous, 243
 perceptive region of, 373
 tooth, 286
 work of, 243-245
 Root hair, 244-245
 Rosa, 312
 Roses, 239, 505, 515
 Ross, 406
 Rotifers, 89, 103, 413
 Roundworms, 87, 103, 219
 Roux, Wilhelm, 527, 632
 Rubner, 312
 Rugae, 289
 Rumen, 288
 Ruminant stomach, 288
 Russian thistle, adaptations for seed scattering, 39
 Rusts, 228

 Saccharomyces, 71
 Saccharomycetes, 71
 Sacculina, 500
 Sagitta, 93
 Salamanders, 103, 109
 Salivary glands, 293
 Salmon
 egg-laying habits of, 596-597
 depletion of, 597
 Sanborn, 453
 Saprolegnia, 71
 Saprophytic nutrition, 281
 Saprophytism, effect on biological adaptations, 492
 Sap-wood, 246, 247
 Sarcodina, 77
 Sarcolemma, 338
 Sauropsida, 507
 Scab mites, 216
 Scandinavians, 562
 Scaphopoda, 97
 Scarlet fever, 633-634
 Scavengers, 52-53
 Schaeffer, A. A., 382
 Schick test, 633
 Schizogony, 227
 Schizomycetes, 71
 Schlerenchyma, 247
 Schuchert, estimate of geological time by, 553
 Schwann's sheath, 340
 Sclerotic coat, 359
 Scolex, 226
 Scorpions, 500, 514
 Scott, W. B., 510
 Scurvy, 278
 Scyphozoa, 81
 Sea-anemones, 81
 Sea-cows, 117
 Sea-cucumbers, 95
 Sea-lilies, 328
 Sea-urchins, 95, 103, 334, 459, 485, 505, 531
 Sea-walnuts, 83
 Secondary oöcyte, 430
 Secondary sexual characters, 398
 Secondary spermatocyte, 430
 Secretin, 310, 392
 Sedges, 506
 Sedimentary rocks, 475
 Seed, 435, 490
 formation of, 62, 270-272
 methods of scattering, 39
 uses of, 272
 Segmentation, 294
 Segregation, 447, 450
 Selaginella, 75
 Selection, 452
 artificial, 452
 germinal, 527
 mass, 453
 natural, 443, 452
 progeny, 453
 sexual, 527
 Sella turcica, 350
 Semicircular canal, 361
 Semilunar valves, 304, 308
 Seminal receptacles
 bee, 212
 earthworm, 196
 Seminal vesicles
 bee, 212
 earthworm, 196
 Semper, 436
 Sense organs, 498
 Sensitive plant, responses in, 373-374
 Sensitivity, definition of, 127
 Sepals, 497
 Septa, earthworm, 188, 189
 Serology, 514
 Serosa, 290
 Serum, 311
 Setae, 188, 193, 334
 Sex, 465, 470
 beginnings of, in algae, 169-172

- Sex chromosomes, 429
 Sex determination, 467, 471
 Sex hormones, 471
 Sex reversal, 471
 Sexual reproduction
 invertebrates, 411
 vertebrates, 414
 Sexual selection, 527
 Shaler, 531
 Shark sucker, 56
 Shaw, G. B., 527
 Sheep, 509, 515, 519
 effect of, grazing on trees, 20
 Shelford, V. E., 6, 27
 Shellfish, destruction of, 598
 Shells, 493
 Shin-bone, 332
 Shrews, 534
 Shrubs, 240, 493
 Sight, insect, 205, 206
 Silicon, 277
 Silurian period, 476, 513
 Simian shelf, 551
 Simple reflex arc, 341
 Sinanthropus, 556
 Siphonaptera, 102
 Sirenia, 117
 Skates, 423
 Skeletal devices, 327
 Skeletons, 234, 498
 appendicular, 329, 332
 axial, 329, 332
 for protection, 334
 for support, 333
 functions of, 333
 human, 331
 kinds of, 328
 use in movement, 334
 visceral, 329
 Skin, 322
 Skin color, 563
 Skull, 329, 345
 bones of human, 330
 Slime fungi, 71
 Slime molds, 71
 Sloth, 508
 Slugs, 97, 103
 Small intestine, 291
 Smallpox, 628-629
 Smell, 357, 545
 Smiley and Gould, 611
 Smith, Wm., 480
 Smuts, 73, 228
 Snails, 97, 103, 328, 334, 436, 523, 531
 Snakes, 103, 111, 490, 499, 533
 Snake venom, antitoxin against, 634
 Snapdragon, 239
 Social life, 492
 Sodium, 277
 Soft palate, 284
 Soil, 435
 acid and alkali, effects, 15
 Solar plexus, 354
 Sollas, estimate of geological time by, 553, 554
 Soma cells, 412
 Somatic characters, 450
 Somatoplasm, 438, 453
 Somatopleure, 426
 Somites, 425 (See Metameres)
 Space, 473
 Spallanzani, 406
 Spaniards, 561
 Sparrows, 520
 Species, 506
 concept of, 66-69
 history of, 64-69
 Species Plantarum, 65
 Speech, 551
 Speman, 432
 Sperm, 466
 Spermary, 412
 Spermatids, 430
 Spermatocyte, primary, 429
 Spermatogenesis, 428
 Spermatogonia, 428
 Spermatozoa, 415
 Spermists, 467
 Sphagnum, 73
 Sphenisciformes, 113
 Sphenodon, 111
 Sphenopsida, 75
 Sphincter, pylorus, 289
 Spicules, 334
 Spiders, 48, 99, 102, 103, 500, 514, 520, 532
 Spinal column, 329
 Spinal cord, 341, 353
 Spinal nerves, 353
 Spines, 493
 Spiny-headed worm, 219
 Spiracles, 315
 insect, 210
 Spiral valve, 283
 Spireme, 141, 143
 Spirillum, 71, 165
 Spirogyra, 69, 170-171
 conjugation, 170
 Splanchnic layer, 419
 Splanchnopleure, 426
 Splenic fever, 622
 Sponges, 79, 103, 328, 334, 342, 491, 531
 Spongilla, 79
 Spontaneous generation, 406
 Sporangia, mold, 173, 174
 Sporangiothores, 173, 174
 Spores, 490
 Sporocysts, 414

- Sporophyte generation, evolution of, 178
- Sporophytes, 498
- Sporozoa, 77
- Sporozoite, 227, 228
- Squamata, 111
- Squids, 97
- Squirrels, 550
- Stackman, E. C., 582
- Stamens, 497
- Staphylococcus, 71
- Starch, manufacture of, in green leaves, 253
- Starfish, 67, 95, 103, 328, 334, 335, 336, 343, 344, 549
- Starling, 392, 519
- State conservation departments, 602, 603
- Statoblasts, 491
- Statocyst, 361, 372
- Stegocephalia, 109
- Stem
 passage of liquid through, 245
 structure and function of, 245-251
- St. Martin, Alexis, 290
- Stentor, 77
- Sterility, 471
- Sternberg, 482
- Sternum, 331
- Stickleback, 47
- Stigma, 61
- Stimuli
 classification of, 367
 definition of, 366
- Sting, bee, 212
- Stingers, 493
- Stolens, mold, 173, 174
- Stomach, 288, 289
- Stomata
 cross section of, 267
 movement of guard cells, 267-268
 structure of, 251, 252, 267
- Stone canal, 336
- Stone cells, 247
- Stonewarts, 71
- Stony corals, 334
- Storks, 113, 493
- Strains, molds, 174
- Stream association, 3, 4
- Strepsiptera, 101
- Streptococcus, 71
- Struggle for existence, 334, 518, 520
- Struthioniformes, 113
- Styela, 432
- Style, 61
- Stylonychia, 77, 335, 342
- Suberin, 247, 264
- Subesophageal ganglion, 344
 bee, 211
- Submaxillary gland, 293
- Submucosa, 289
- Subnasale, 563
- Successions, 32-34
- Succus entericus, 297
- Sullivan, 562, 563, 564
- Sulphur, 277
- Summer, experiments of, with flounders, 370
- Sundew, 54
- Sunflowers, 505
- Superior vena cava (precava), 307
- Supraesophageal ganglion, 344
 bee, 211
 earthworm, 194
- Survival, 518, 521
- Swarming, bees, 214
- Swiss, 561
- Symbiosis, 54-56, 490
- Symmetry, 67, 69
 bilateral, 485, 532
 radial, 485, 531
- Synapse, 341
- Synapsis, 460, 467, 459
- Syrians, 561
- Systema Naturae, 65
- Systemic circulation, 309
- Systems, 506
- Taenia, 85
- Taenia saginata, 226
- Taenia solium, 226
- Tail, 329
- Tail fold, 426
- Tail piece, 415, 416
- Takamine, 393
- Tapeworms, 85, 103, 219, 229
 bass, 229
 beef, 226
 broad, of man, 229
 pork, 226
 taenioid, 226
- Tapir, 508
- Tarsal bones, 332
- Tarsius, 535, 536
- Tarsus, insect, 206, 207
- Taxonomy, 64-117, 504
- Taste bud, 356
- Tea, annual production of, 574
- Teeth, 286, 488, 496
 garpike, 285
 shark, 285
- Telencephalon, 346, 347
- Telophase, 142, 143
- Teleostei, 107
- Temperature, 490
 optimum, 9
- Tendon, 338
- Termites, 100

- Testis, 415
 Tetanus, 396, 634
 Tetrads, 176
 Tetrapoda, 68, 109
 Texas fever, 620
 Thallophyta, 69
 Thallophytes, 168
 Theophrastus, 570
 Theridium, 520
 Thistles, 493, 505
 Threadworms, 87
 Thoracic basket, 329, 330
 Thoracic cavity, 318
 Thoracic duct, 298, 304
 Thoracicolumbar, 354
 Thoracic segments, insect, 201
 Thorax, 543
 bee, 202, 206-208
 Thymus, 398
 Thyone, 95
 Thyrotropic hormone, 401
 Thyroid, 394, 395, 396, 397
 Thyroxin, 394
 Thysanoptera, 101
 Thysanura, 99
 Tibia, 332
 insect, 206, 207
 Tick, 620
 Tidal shore habitat, 18
 Time, 473, 553
 Time-scale, 476
 Tissue formation, 422
 Tissues
 animal, 146-148
 circulatory, 146, 147, 148
 classification of, 144
 conducting, 145, 146
 epithelial, 146, 147
 fundamental, 144, 145
 meristemic, 145, 146
 muscular, 146, 147
 nervous, 146, 148
 plant, 144, 145, 146
 protective, 144, 145
 reproductive, 146, 148
 supporting, 146, 147
 Tmesipteris, 75
 Toad, 492
 economic value of, 577
 Toadstool, 519
 Tools, 546, 550
 Totipotent eggs, 432
 Touch, 545
 Toxin-antitoxin, 633
 Toxoid, 633
 Trachea, 317
 Tracheae, insects, 210
 Tracheal system, 302
 of worker bee, 210
 Tracheophyta, 75
 Tracks, 479
 Traits, 640
 Translocation, 457
 Transpiration, 266-268
 experiments to show, 266
 loss of water by, 267
 Transverse commissure, 344
 Tree, 240
 Tree shrews, 534, 540
 Trees, 493
 Trematoda, 85, 219
 Trematode, complex cycle of, 231
 Triassic period, 476, 513
 Triceps, 338
 Trichamophora, 71
 Trichinella, 87, 615
 Trichinella spiralis, 225
 life cycle of, 226
 Trichocysts, 158
 Trichoptera, 102
 Tricuspid valve, 307
 Trihybrids, 447, 448, 449
 Trilobites, 513
 Triploblastic, 68
 Trochanter, 206, 207
 Trochelmintbes, 89, 103
 Tropical rain forest, 28
 Tropisms, 364, 367-369
 Trypanosoma, 77, 103
 Trypanosomes, 220, 620
 Trypsin, 295
 Tschermak, 443
 Tsetse fly, 511
 Tube-feet, 336, 344
 Tuberculosis
 bovine, 623
 cause of, 623
 cure for, 624
 death rate of, 623, 624
 Tuna, 545
 Tunicates, 105, 329, 499
 Tupaia, 534
 Turbellaria, 85
 Turks, 561
 Turk's saddle, 350
 Turkeys, 114
 Turtles, 103, 111, 328, 334, 514
 Twins, identical, 471
 Twixt-brain, 346, 348
 Tympanic membrane, 362
 Tyndall, 407
 Typhlosole, earthworm, 189, 283
 Typhoid, 629-630
 Typhoid Mary, 490, 630
 Typhus, 619-620
 Ulna, 332
 Ulopteryx, 71

- Ulothrix, 69
 - structure of, 171
- Ulva, 69
- Umbilical cord, 428
- Undulating membrane, 159
- Unguiculata, 115
- Ungulata, 117
- Ungulates, 487, 514, 534
- Unguligrade feet, 333
- Unit characters, 450
- United States Bureau of Fisheries, 598-599
- United States Department of Agriculture, 571, 573, 577, 578, 585, 587
- Urea, 296, 310, 322
- Ureter, 323
- Urethra, 324
- Urochordata, 104, 105
- Urodela, 109
- Use and disuse, 516
- Uvula, 284
- Vaccination, smallpox, 628
- Vaccines, 631-632
- Vacuoles, 129
- Vagina, bee, 212
- Vagus, 318, 352
- Vampire, 508
- Van Helmot, 241
- Van Leeuwenhoek, 151-152, 153
- Vasa efferentia, earthworm, 196
- Vascular rays, 248-249
- Vas deferens, earthworm, 196
- Vasomotor center, 310
- Variation, 417, 442, 518, 519
- Vaucheria, 69
- Vectors, insect, 618-620
- Veddahs, 561
- Veins, 302, 303, 304, 305
 - leaf, 250, 251-252
- Venereal diseases, 634-635
- Ventral diaphragm, insect, 210
- Ventricle, 306, 348, 350, 351
- Venules, 303
- Vermis, 350
- Vesalius, 305
- Vessels, lymph, 304
- Vestigial structures, 499, 501
- Vermiform appendix, 499
- Vertebrae, 330
 - caudal, 330, 331
 - cervical, 331
 - lumbar, 331
 - sacral, 331
 - thoracic, 331
- Vertebral column, 328, 345
- Vertebrata, 105
- Vertebrates, 103, 105, 233, 334, 336, 532
- Vicuña, 509
- Villus, 291, 428
- Vincent, 611
- Violets, 506
- Vision, 545
- Vitamin A, 278
- Vitamin B, 278
- Vitamin C, 278
- Vitamin D, 278, 279
- Vitamin E, 278
- Vitamin G, 278
- Vitamins, 265, 277
 - antineuritic, 278
 - antipellagric, 278
 - antirachitic, 279
 - antiscorbutic, 278
 - antisterility, 279
- Vitreous humor, 360
- Voit, 312
- Volvox, 67, 179
- Von Baer, 502
- Von Bering, 632-633
- Von Frisch, 204
- Von Höhnel, 267
- Von Mering, 397
- Von Sachs, 241, 269
- Vorticella, 77
- Walcott, estimation of geological time by, 553
- Wallace, A. F., 518, 519
- Walter, H. E., 385
- Ward, Henshaw, 486, 529
- Ward, H. B., 10
- Warm receptors, 363
- Warning colors, 492
- Wart hog, 508
- Water
 - amount in living things, 133, 254
 - rise of, in plants, 269
 - role of, in plant life, 255, 256
- Water fleas, 413
- Water vascular systems, 335, 336
- Weapons, 547, 550
- Weaver, 243
- Weed seeds, 40
- Weeds, 40, 519
- Weismann, 517, 523, 526
- Wells, 553
- Wells, Huxley, and Wells, 383
- Whale, 117, 490, 498, 499, 514, 521, 534, 535, 545
- Wheat, 454, 573
- Wheat rust, 73, 228
- White matter, 350, 353
- Widal test, 626, 627
- Wiedersheim, 497
- Willughby, 64
- Wings, bee, 206

- Winter eggs, 491
Witch-hazel, 505
Wolf, 477
Wood, Dr., 611
Woodruff, 417
Worker bee
 lateral view, 202
 mouth parts, 205
Worms, 499, 531
 round, 219
 spiny-headed, 219
 tape, 219
Wrist, 544

Xanthophyll, 258
X-chromosome, 468
Xerophytes, 6
Xiphidium, 467
Xylem, 243, 245, 248, 250

Y-chromosome, 468, 469
Yeast, 71
Yellow fever, 619
Yellow spot, 360
Yerkes, R. M., 387, 538
Yolk sac, 423, 424, 488, 501
Yolk stalk, 426

Zebra, 508
Zonal distribution, 42
Zoochlorellae, 180
Zoology, systematic, 64
Zoospores, 47
 Ulothrix, 171
Zucker, 279
Zygnion, 563
Zygospores, Spirogyra, 170
Zygotes, 417
 Closterium, 164-165
 Spirogyra, 171

